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DEVELOPMENT TEST OF THE THIOKOL TE-M-616-01 SOLID-PROPELLANT ROCKET MOTOR

H. L. Merryman

ARO, Inc.

August 1973

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**ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE**

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SOLID-PROPELLANT ROCKET MOTOR**

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FOREWORD

The test program reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under sponsorship of the National Aeronautics and Space Administration (NASA), Goddard Space Flight Center (GSFC), for the Thiokol Chemical Corporation (TCC) under Program Element 920X.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in Propulsion Development Test Cell (T-3) of the Engine Test Facility (ETF) on March 24, 1973, under ARO Project No. RA202-C, and the manuscript was submitted for publication on June 13, 1973.

This technical report has been reviewed and is approved.

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ABSTRACT

One Thiokol Chemical Corporation TE-M-616-01 solid-propellant rocket motor was successfully fired at an average simulated altitude of 103,000 ft while spinning at 105 rpm after being temperature conditioned at $5 \pm 5^{\circ}\text{F}$ for a minimum of 34 hr. In addition, the aft six inches of the nozzle exit cone was cooled to about -195°F immediately prior to ignition. The program objectives were to determine vacuum ballistic performance, altitude ignition characteristics, motor temperature-time histories, structural integrity of motor components, and the lateral (nonaxial) thrust vector. The applicable data were used to demonstrate compliance of the motor with requirements set forth in Communication Research Centre Specification SS09-04.

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NOMENCLATURE

A_{ex}	Nozzle exit area, in. ²
A_t	Nozzle throat area, in. ²
C_F	Average vacuum thrust coefficient, based on action time (t_a) and the average of prefire and postfire nozzle throat area
\bar{c}_f	Vacuum thrust coefficient over a selected 1-sec interval of motor operation just prior to tailoff
F	Measured axial thrust, lbf
F_i	Maximum thrust at ignition
$I_{vac_{action}}$	Vacuum impulse based on action time (t_a), lbf-sec
$I_{vac_{total}}$	Vacuum impulse based on total time (t_T), lbf-sec
P_{cell}	Measured cell pressure, psia
P_{ch}	Measured chamber pressure, psia
t_a	Action time, time interval from first indication of thrust until the delivery of 99.5 percent of total impulse, sec

t_{bd}	Time of nozzle flow breakdown, sec
t_i	Ignition time, time interval from application of voltage to the igniter to the time chamber pressure has risen to 200 psia, sec
t_T	Total time, time interval between the first indication of chamber pressure at ignition and ending, when chamber pressure reaches 1 psia on the descending portion of the pressure versus time curve, sec

SECTION I INTRODUCTION

The Thiokol Chemical Corporation (TCC) TE-M-616-01 solid-propellant rocket motor is to be used as the apogee kick motor for the Communications Technology Satellite (CTS) (Ref. 1). The kick motor is to impart the required impulse for injection of the CTS spacecraft into a circular synchronous earth orbit at the apogee of an elliptical transfer orbit.

The test program reported herein was a portion of the development test phase for the TE-M-616-01 motor. The test objectives were to determine the vacuum ballistic performance, altitude ignition characteristics, motor component structural integrity, motor temperature-time histories, and the lateral (nonaxial) thrust component. The motor was fired while spinning about its axial centerline at 105 rpm, following temperature conditioning at $5 \pm 5^\circ\text{F}$ for a minimum of 34 hr prior to testing. The aft six inches of the nozzle exit cone was cooled to about -195°F immediately prior to ignition.

Motor vacuum ballistic performance, altitude ignition characteristics, motor temperature-time histories, motor component structural integrity, and the lateral (nonaxial) thrust data are presented and compared with the applicable requirement set forth in Communication Research Centre Specification SS09-04 (Ref. 2).

SECTION II APPARATUS

2.1 TEST ARTICLE

The Thiokol Chemical Corporation TE-M-616-01 solid-propellant rocket motor (Fig. 1, Appendix I) is a full-scale, flightweight motor having the following nominal dimensions and burning characteristics at 70°F :

Length, in.	48.6
Diameter, in.	27.3
Loaded Weight, lbm	799.0
Propellant Weight, lbm	734.8
Maximum Thrust, lbf	6624.0
Maximum Chamber Pressure, psia	538.0
Burn Time, sec	34.8
Throat Area, in. ²	6.995
Nozzle Area Ratio, A_{ex}/A_t	42.0

The spherical motor case is constructed of 0.033-in. forged titanium (6 AL-4V). The case is lined internally with TCC TL-H-304 liner and insulated with TIR-300 asbestos-polyisoprene. A stress relief boot assembly is contained in both the forward and aft end of the motor case (Fig. 1a). A flange on the aft end of the motor case provides

for attachment to the CTS spacecraft. The nozzle assembly contains a Graph-I-Tite® G-90 graphite throat insert pinned and bonded to the nozzle adapter flange. The expansion cone is constructed of tape-wrapped carbon phenolic. The nozzle assembly has a nominal 42:1 area ratio and a 14.66-deg half-angle at the exit plane. A closure was bonded in the expansion cone but was punctured prior to testing so that the motor chamber pressure was equal to test cell pressure at motor ignition.

The TE-M-616-01 rocket motor contains a composite propellant grain formulation designated TP-H-3135 (ICC class B) cast in an eight-point-star configuration.

A portion of the spacecraft/motor insulation material was installed around the aft hemisphere (Fig. 1b).

Ignition was accomplished by one pyrogen igniter which, in the flight configuration, incorporates two through-bulkhead initiators (TBI), two explosive transfer assemblies (ETA), and a single electromechanical safe-and-arm (S/A) device. For the test reported herein only one TBI and one ETA were used. The pyrogen assembly contained 7 gm of BKNO_3 pellets (size 2A) to initiate the 0.565-lbm igniter grain.

2.2 INSTALLATION

The motor assembly was cantilever mounted from the spindle face of the spin fixture assembly in Propulsion Development Test Cell (T-3). The spin assembly was mounted on a thrust cradle, which was supported from the cradle support stand by three vertical and two horizontal double-flexure columns (Fig. 2). The spin fixture assembly consists of a 10-hp squirrel-cage-type drive motor, a thrust bearing assembly, and a 46-in.-long spindle having a 36-in.-diam aft spindle face. The spin fixture rotated counterclockwise, looking upstream. Electrical leads to and from the igniters, pressure transducers, and thermocouples on the rotating motor were provided through a 170-channel slipping assembly mounted between the forward and aft bearing assemblies of the spindle. Axial thrust was transmitted through the spindle-thrust bearing assembly to two double-bridge strain-gage-type load cells mounted just forward of the thrust bearing on the motor axial centerline.

Preignition pressure altitude conditions were maintained in the test cell by a steam ejector operating in series with the ETF exhaust gas compressors. During the motor firing, the motor exhaust gases were used as the driving gas for the 37-in.-diam ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial force, motor chamber pressure, lateral (nonaxial) force, test cell pressure, motor case, and nozzle temperatures, and motor rotational speed. Table I (Appendix II) presents instrument ranges, recording methods, and measurement uncertainty for all reported parameters.

The axial force measuring system consisted of two double-bridge, strain-gage-type load cells mounted in the axial double-flexure column forward of the thrust bearing on the spacecraft centerline. The lateral (nonaxial) force measuring system consisted of two double-bridge, strain-gage-type load cells installed forward and aft between the flexure-mounted cradle and the cradle support stand normal to the rocket motor axial centerline and in the horizontal plane passing through the motor axial centerline (Fig. 2d).

Unbonded strain-gage-type transducers (0- to 1-psia) were used to measure test cell pressure. Bonded strain-gage-type transducers with ranges from 0 to 50 and 0 to 1000 psia were used to measure motor chamber pressure. Chromel®-Alumel® (CA) thermocouples were bonded to the motor case and nozzle (Fig. 3) to measure surface temperatures during and after motor burn time. Rotational speed of the motor assembly was determined from the output of a magnetic pickup.

The output signal of each measuring device was recorded on independent instrumentation channels. Primary data were obtained from four axial thrust channels, two test cell pressure channels, and three motor chamber pressure channels. These data were recorded as follows: Each instrument output signal was indicated in totalized digital form on a visual readout of a millivolt-to-frequency converter. A magnetic tape system, recording in frequency form, stored the signal from the converter for reduction at a later time by an electronic computer. The computer provided a tabulation of average absolute values for each 0.10-sec time increment and total integrals over the cumulative time increments.

The output signal from the magnetic rotational speed pickup was recorded in the following manner: A frequency-to-analog converter was triggered by the pulse output from the magnetic pickup and in turn supplied a square wave of constant amplitude to the electronic counter, magnetic tape, and oscillograph recorders. The scan sequence of the electronic counter was adjusted so that it displayed directly the motor spin rate in revolutions per minute.

The millivolt outputs of the lateral (nonaxial) force load cells and thermocouples were recorded on magnetic tape from a multi-input, analog-to-digital converter and reduced to engineering units by an electronic computer.

A recording oscillograph was used to provide an independent backup of all operating instrumentation channels except the temperature and radiation measurement systems. Selected channels of thrust and pressures were recorded on null-balance, potentiometer-type strip charts for analysis immediately after a motor firing. Visual observation of the firing was provided by a closed-circuit television monitor. High-speed, motion-picture cameras provided a permanent visual record of the firings.

2.4 CALIBRATION

The thrust system calibrator weights, thrust loads cells, and pressure transducers were laboratory calibrated prior to usage in this test. After installation of the measuring devices

in the test cell, the thrust load cells were again calibrated at sea-level, nonspin ambient conditions and also at simulated altitude while spinning at 105 rpm.

The pressure recording systems were calibrated by an electrical, four-step calibration using resistances in the transducer circuits to simulate selected pressure levels. The axial thrust instrumentation systems were calibrated by applying to the thrust cradle known forces, which were produced by deadweights acting through a bell crank. The calibrator is hydraulically actuated and remotely operated from the control room. Thermocouple recording instruments were calibrated by using known millivolt levels to simulate thermocouple outputs.

After the motor firing, with the test cell still at simulated altitude pressure, the recording systems were recalibrated to determine any shift.

Calibrations of the lateral (nonaxial) force measuring system were conducted using the procedure outlined in Ref. 3.

SECTION III PROCEDURE

The TCC TE-M-616-01 rocket motor (S/N D2) arrived at the AEDC on November 7, 1972. The motor was visually inspected for possible shipping damage and radiographically inspected for grain cracks, voids, or separations and found to meet criteria provided by the manufacturer.

After radiographic inspection, the motor was stored in an area temperature conditioned at $70 \pm 5^\circ\text{F}$ where the motor was checked to ensure correct fit of mating hardware, thermocouples were bonded to the motor case and nozzle, the electrical resistance of the igniter detonator device was measured, the nozzle exit diameters were measured, and the spacecraft/motor insulation material was installed. The motor was leak checked after installation of the chamber pressure transducers, and the entire assembly was weighed and photographed. After the motor case was secured to the thrust adapter, the assembly was mounted on a spin table, and radial dimensions of selected surfaces were measured as a function of angular position relative to the centerline of the assembly to facilitate alignment with the spin rig spin axis during test cell installation.

After installation of the motor assembly in the test cell, the motor centerline was axially aligned with the spin rig spin axis by rotating the motor assembly and measuring the deflection of the selected surfaces with dial indicators and making appropriate adjustments. The instrumentation connections were made, and the motor assembly was balanced at a rotational speed of 105 rpm. The motor was installed within a cryoplate assembly (Fig. 2b) through which cooled trichloroethylene was circulated to provide the desired thermal environment of $5 \pm 5^\circ\text{F}$. In addition, a cool, dry, gaseous nitrogen purge was circulated within the space between the cryoplates and the motor case to remove water vapor which could condense as frost on the plate internal surfaces.

Immediately before the firing, the aft six inches of the nozzle exit cone was cooled to -195°F with liquid nitrogen circulation through a ring (Fig. 2c).

The final operation prior to firing the motor was to adjust the firing circuit resistance to provide the desired current to the igniter detonator. The entire instrumentation measuring-recording complex was activated, and the motor was fired while spinning (under power) at 105 rpm.

Spinning of the motor was continued for approximately 60 min after burnout, during which time motor temperatures were recorded, and postfire calibrations were accomplished. The assembly was decelerated slowly until rotation had stopped, and another set of calibrations was taken. The test cell pressure was then returned to ambient conditions, and the motor assembly was inspected, photographed, and removed to the storage area. Postfire inspection at the storage area consisted of measuring the throat and exit diameters of the nozzle, weighing the motor, and photographically recording the postfire condition of the motor.

SECTION IV RESULTS AND DISCUSSION

One Thiokol Chemical Corporation TE-M-616-01 solid-propellant rocket motor (S/N D2) was successfully fired at an average pressure altitude of 103,000 ft while spinning about the motor axial centerline at 105 rpm. Prior to firing, the motor was temperature conditioned at $5 \pm 5^{\circ}\text{F}$ for a period in excess of 34 hr. Immediately prior to ignition, the aft six inches of the nozzle exit cone was cooled to about -195°F . The program objectives were to determine vacuum ballistic performance, altitude ignition characteristics, motor temperature-time histories, structural integrity of motor components, and the lateral (nonaxial) thrust vector. The applicable data were used to demonstrate compliance of the motor with requirements set forth in Communication Research Centre Specification SS09-04.

Altitude ignition characteristics and vacuum ballistic performance are presented in Table II. Temperature-time histories of the motor case and nozzle are presented and discussed. When multiple channels of equal accuracy instrumentation were used to obtain values of a single parameter, the average values were used to calculate the data presented.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motor was ignited at a pressure altitude of 121,000 ft. The variations of thrust and chamber pressure during motor ignition are presented in Fig. 4. Ignition time, the time interval from application of ignition voltage to the time when chamber pressure has risen to 200 psia, was 0.132 sec which is below the specification maximum time of 0.300 sec.

4.2 ALTITUDE BALLISTIC PERFORMANCE

The variations of thrust, chamber pressure, and test cell pressure with motor burn time are presented in Fig. 5. The motor burning characteristics were as expected.

Since the nozzle does not operate fully expanded at the low chamber pressures encountered during tailoff, the measured total impulse data during this period cannot be corrected to vacuum conditions by adding the product of cell pressure integral and nozzle exit area. Therefore, action time and total time were segmented, and the method used to determine vacuum impulse is illustrated in Fig. 6. The exhaust nozzle flow breakdown was considered to have occurred simultaneously with the exhaust diffuser flow breakdown (as indicated by a rapid increase in cell pressure during motor tailoff burning).

Vacuum total impulse, based on action time (t_a) of 38.9 sec, was 210,949 lbf-sec. Vacuum total impulse, based on total time (t_T) of 43.5 sec, was 212,321 lbf-sec. The specification limits for total time vacuum impulse ranges from 212,850 to 217,150 lbf-sec which shows that motor S/N D2 was 529 lbf-sec lower in impulse than the minimum allowable limit. Vacuum specific impulse based on manufacturer's stated propellant weight and total time was 288.94 lbf-sec/lbm.

4.3 STRUCTURAL INTEGRITY AND TEMPERATURE DATA

Postfire examination of the motor case and nozzle assemblies and the spacecraft/motor insulation material did not reveal any evidence of thermal damage (Fig. 7). The pre- to postfire nozzle throat area increased 10.5 percent, and the nozzle exit area decreased about 0.01 percent (Table III).

Motor case and nozzle temperature variations with time are presented in Fig. 8. The maximum motor case temperature was about 500°F (TC-6A, Fig. 8c and TC-6B, Fig. 8d) and occurred 300 sec after motor ignition. These values are below the specification maximum allowable of 700°F.

4.4 LATERAL (NONAXIAL) THRUST VECTOR MEASUREMENT

A primary objective of this test was to measure the motor thrust misalignment. This objective was accomplished by measuring the lateral component of the axial thrust. The recorded lateral thrust data were corrected for installation and/or electronic effects as described in Ref. 4. The resultant data are presented in Fig. 9.

The maximum magnitude of lateral thrust recorded during the near steady-state portion of motor operation was about 6.6 lbf and occurred about 23.5 sec after motor ignition (Fig. 9). The average magnitude of lateral thrust measurement is about 4.7 lbf.

SECTION V

SUMMARY OF RESULTS

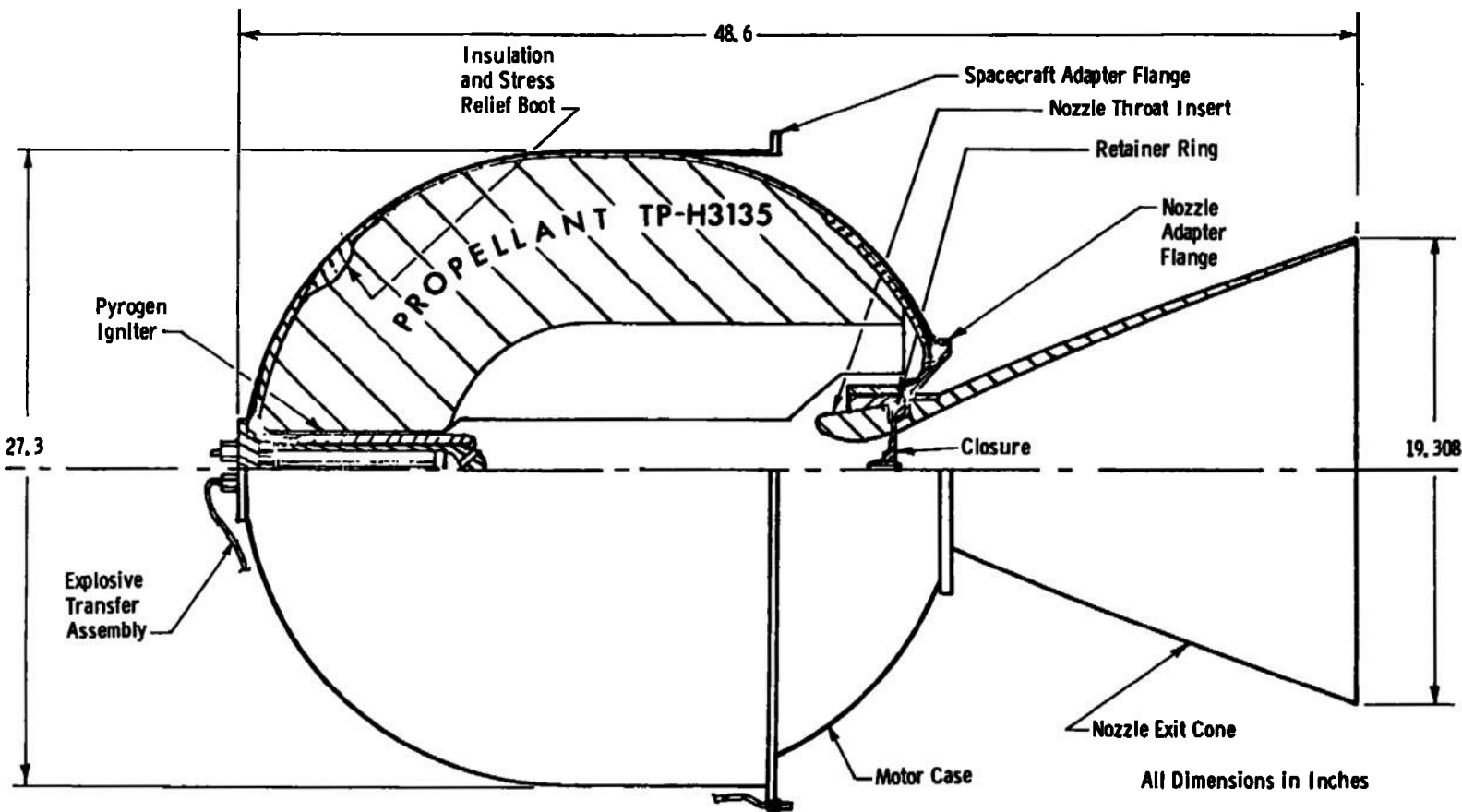
One Thiokol Chemical Corporation TE-M-616-01 solid-propellant rocket motor was successfully fired at an average pressure altitude of 103,000 ft while spinning about the motor axial centerline at 105 rpm following temperature conditioning at $5 \pm 5^\circ\text{F}$ for a minimum of 34 hr. Prior to ignition, the aft six inches of the nozzle exit cone was cooled to about -195°F . The program objectives were to determine vacuum ballistic performance, altitude ignition characteristics, motor temperature-time histories, structural integrity of motor components, and the lateral (nonaxial) thrust vector. The applicable data were used to demonstrate compliance of the motor with requirements set forth in Communication Research Centre Specification SS09-04. The results are summarized as follows:

1. Ignition time, the time interval from application of ignition voltage to the time chamber pressure has risen to 200 psia, was 0.132 sec which is below the specification maximum time of 0.300 sec.
2. Action time, the time interval from first indication of thrust until the delivery of 99.5 percent of total impulse (measured), was 38.9 sec.
3. Total time, the time interval beginning with the first rise in chamber pressure and ending when chamber pressure reached 1 psia on the descending portion of the pressure versus time curve, was 43.5 sec.
4. Vacuum total impulse, based on total time, was 212,321 lbf-sec which is 529 lbf-sec lower than the specification minimum allowable of 212,850 lbf-sec.
5. The maximum measured motor case temperature was about 500°F and is below the specification maximum allowable of 700°F .
6. The maximum magnitude of lateral thrust recorded during the near steady-state portion of motor operation was about 6.6 lbf. The average magnitude of lateral thrust was about 4.7 lbf.
7. Postfire examination of the motor case and nozzle assemblies and the spacecraft/motor insulation material revealed no evidence of thermal damage.

REFERENCES

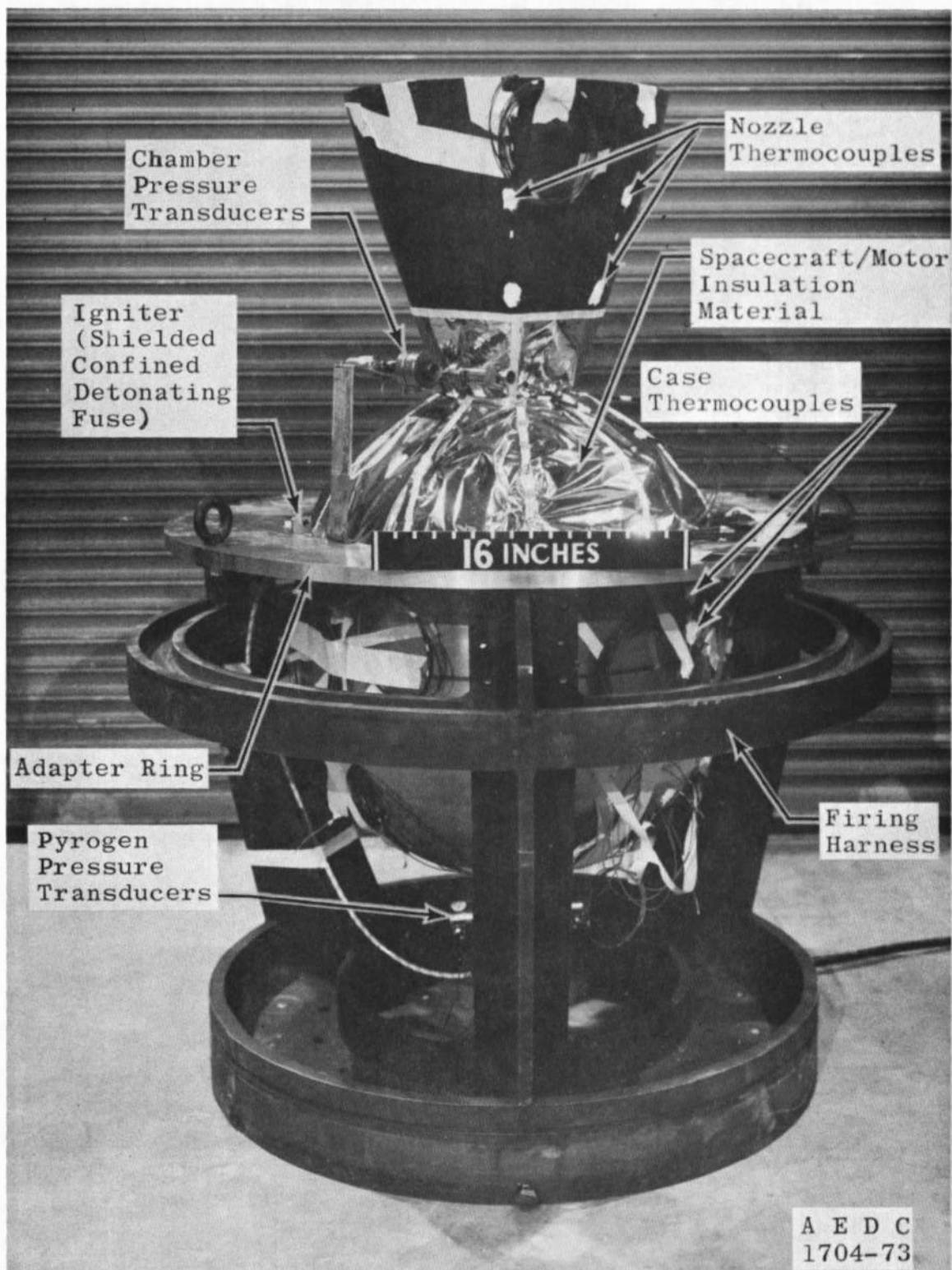
1. Smoyer, J. "TE-M-616-01 Rocket Motor Test Plan." Thiokol Chemical Corporation, Elkton, Maryland, June 7, 1972, Revised November 2, 1972.
2. Eshleman, F. "Requirements, Apogee Motor, Specification SS09-04." Communications Research Centre, Ottawa, Canada, September 29, 1971.
3. Nelius, M.A. and Harris, J.E. "Measurements of Nonaxial Forces Produced by Solid-Propellant Rocket Motors Using a Spin Technique." AEDC-TR-65-228 (AD474410), November 1965.

APPENDIXES
I. ILLUSTRATIONS
II. TABLES

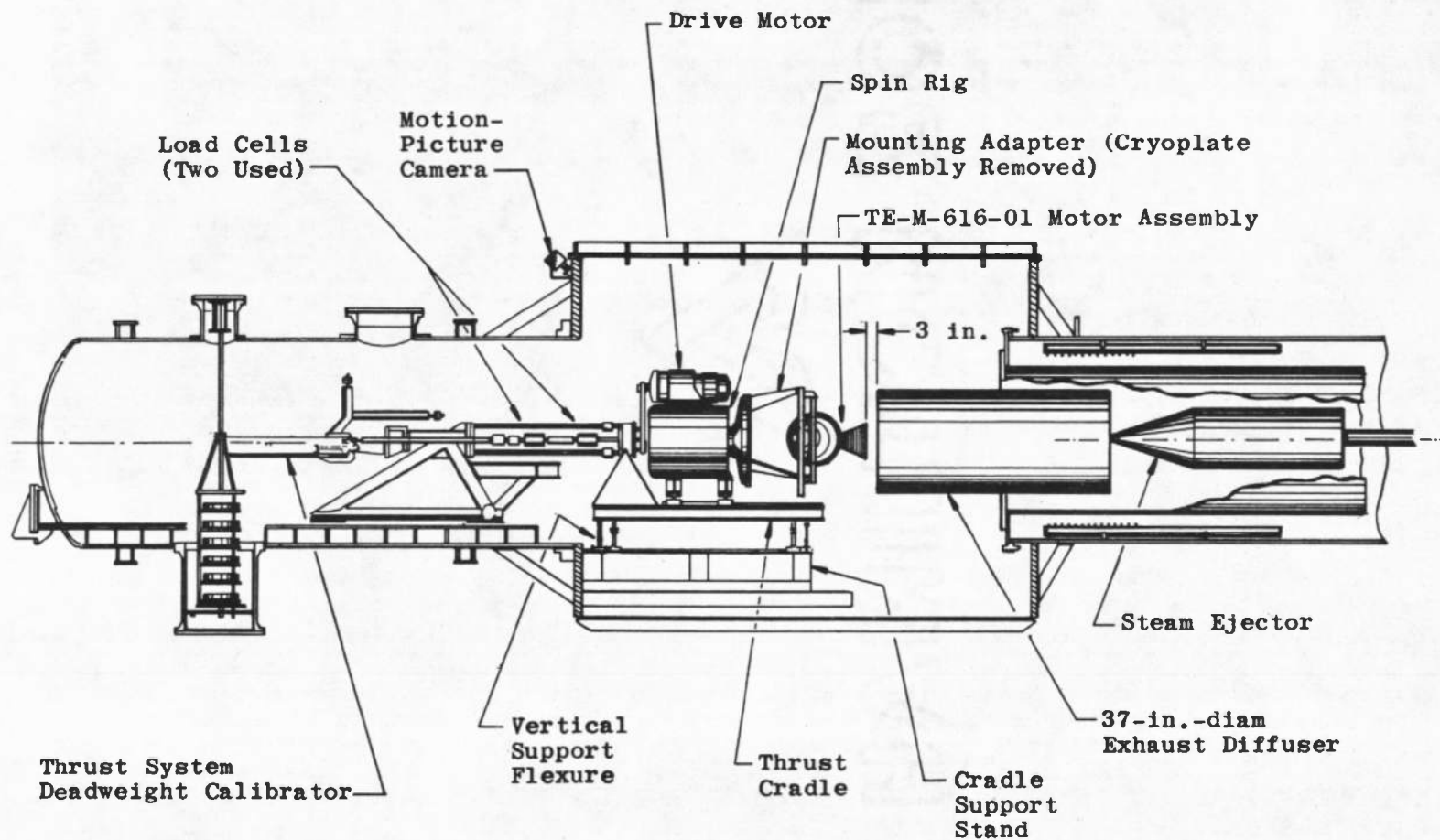


a. Schematic

Fig. 1 Thiokol Chemical Corporation TE-M-616-01 Solid-Propellant Rocket Motor

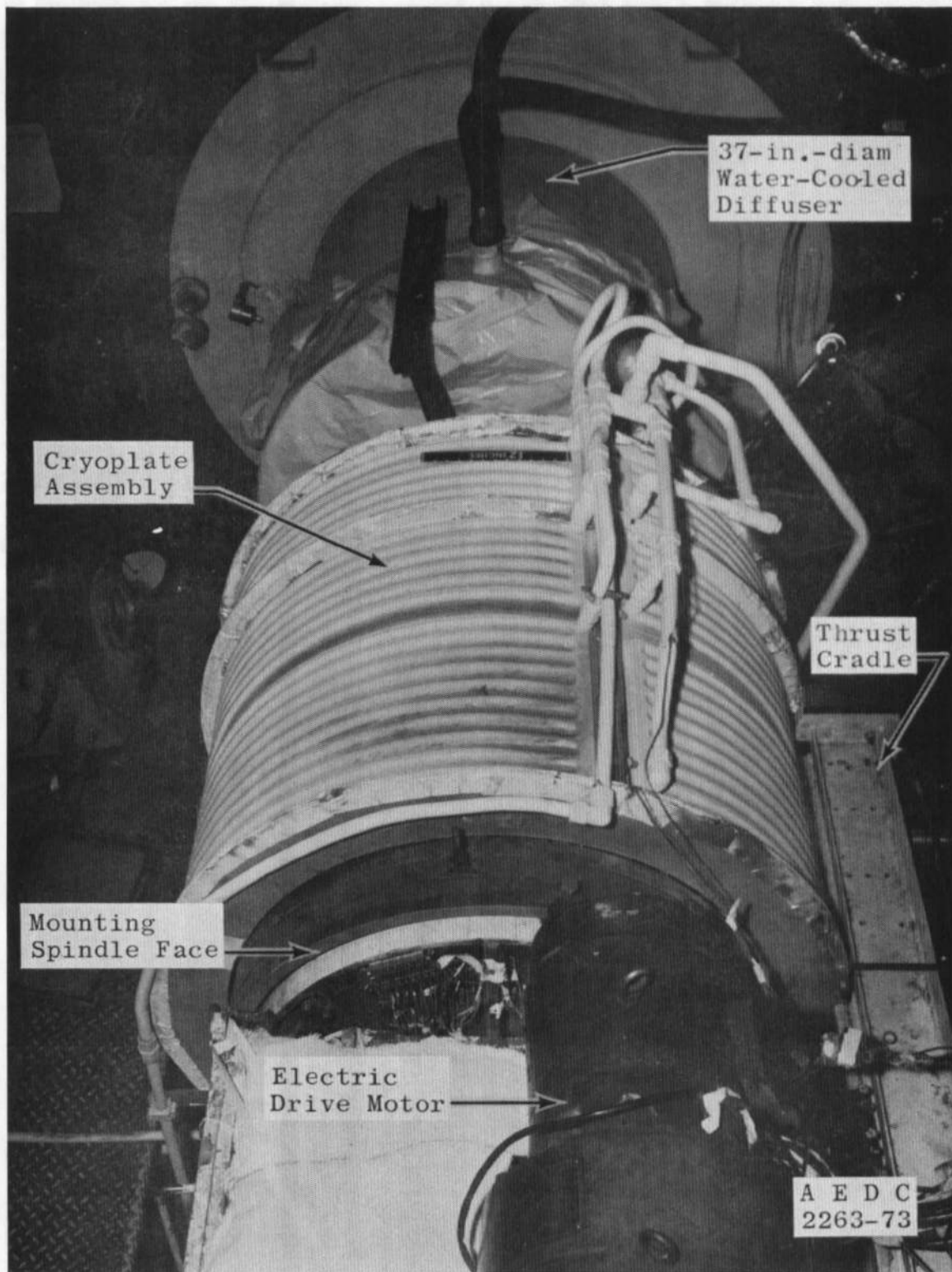


b. Photograph
Fig. 1 Concluded

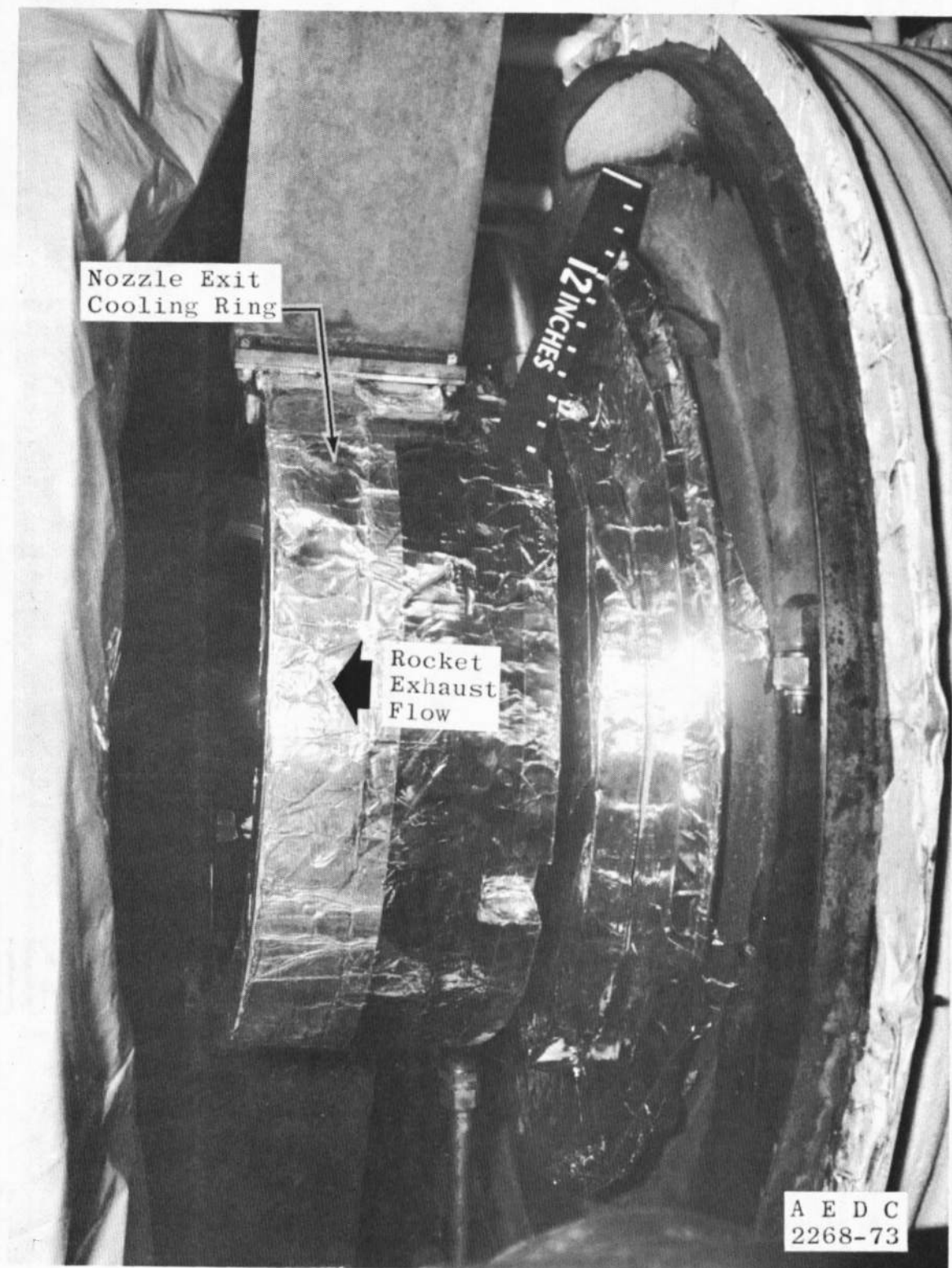


a. Schematic

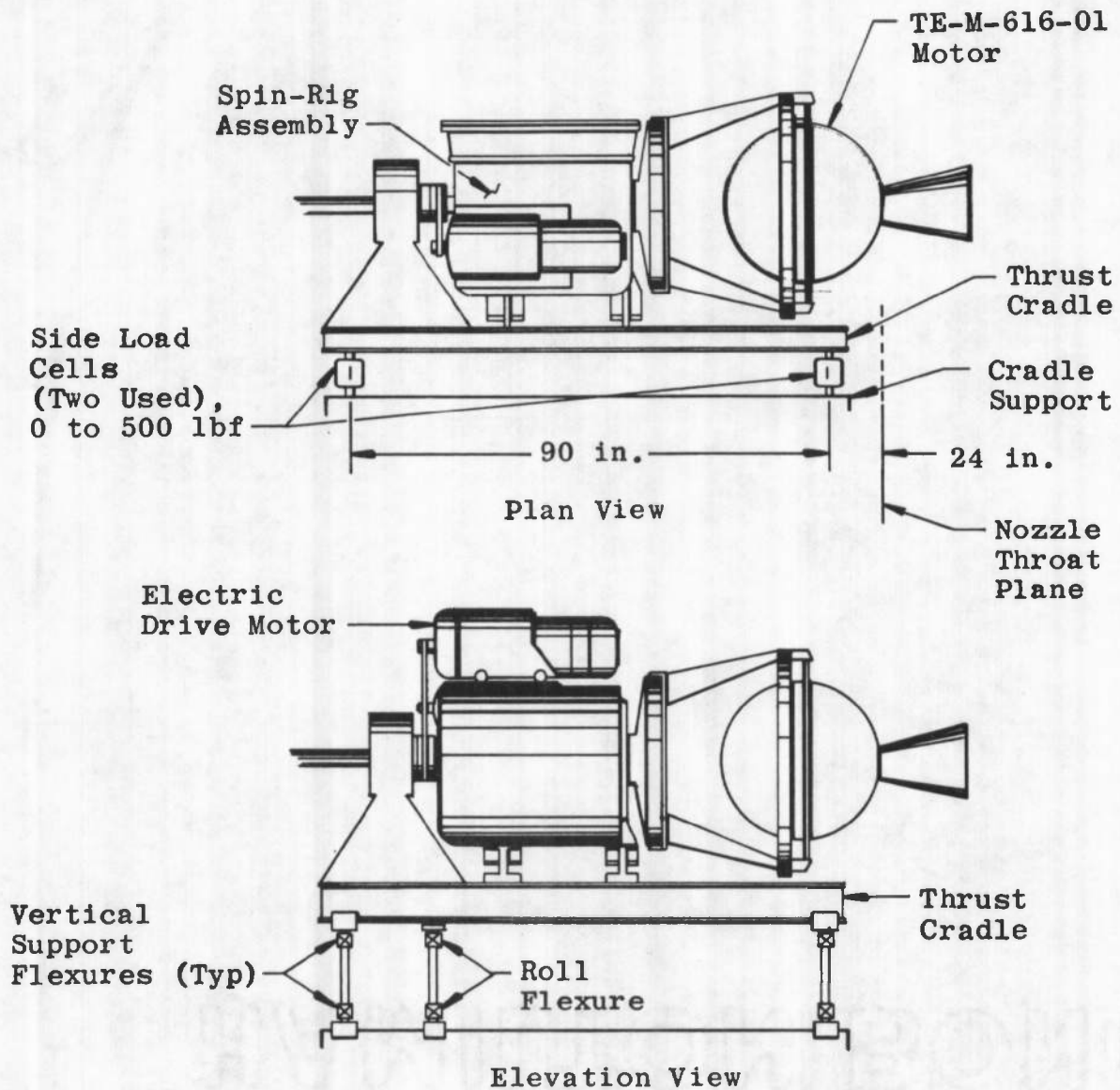
Fig. 2 Installation of the Thiokol TE-M-616-01 Rocket Motor in Propulsion Development Test Cell (T-3)



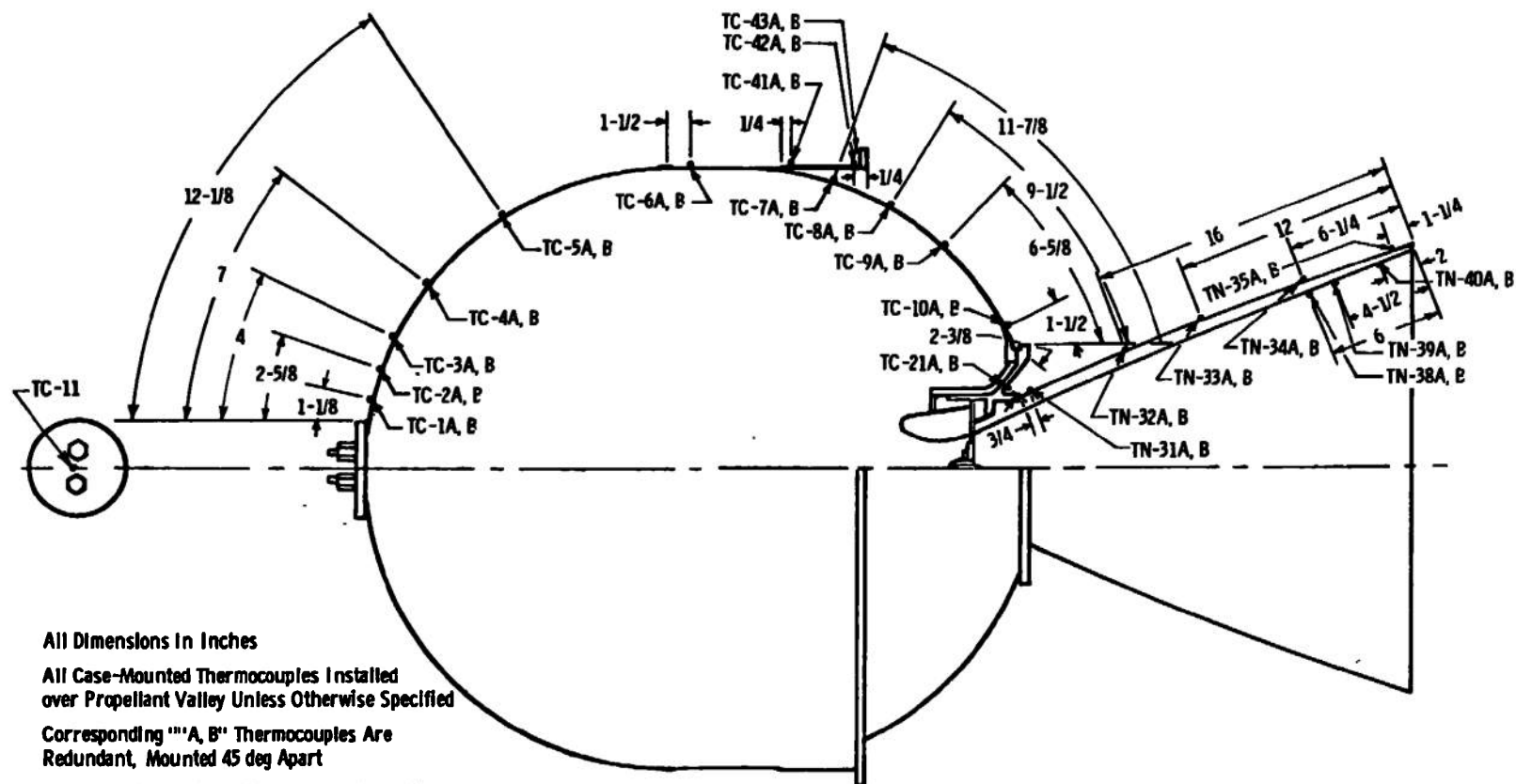
b. Photograph
Fig. 2 Continued



c. Photograph (Nozzle Exit Cooling Ring)
Fig. 2 Continued



d. Detail of Lateral (Nonaxial) Force Measuring System
Fig. 2 Concluded



All Dimensions In Inches

All Case-Mounted Thermocouples Installed
over Propellant Valley Unless Otherwise Specified

Corresponding "A, B" Thermocouples Are
Redundant, Mounted 45 deg Apart

All Circumferential Locations Viewed from Aft
with 0 deg at the "X" Mounting Hole

Primary and Redundant Thermocouples on Inside
Surface of Nozzle are Installed 180 deg Apart

Fig. 3 Schematic of Motor Showing Thermocouple Locations

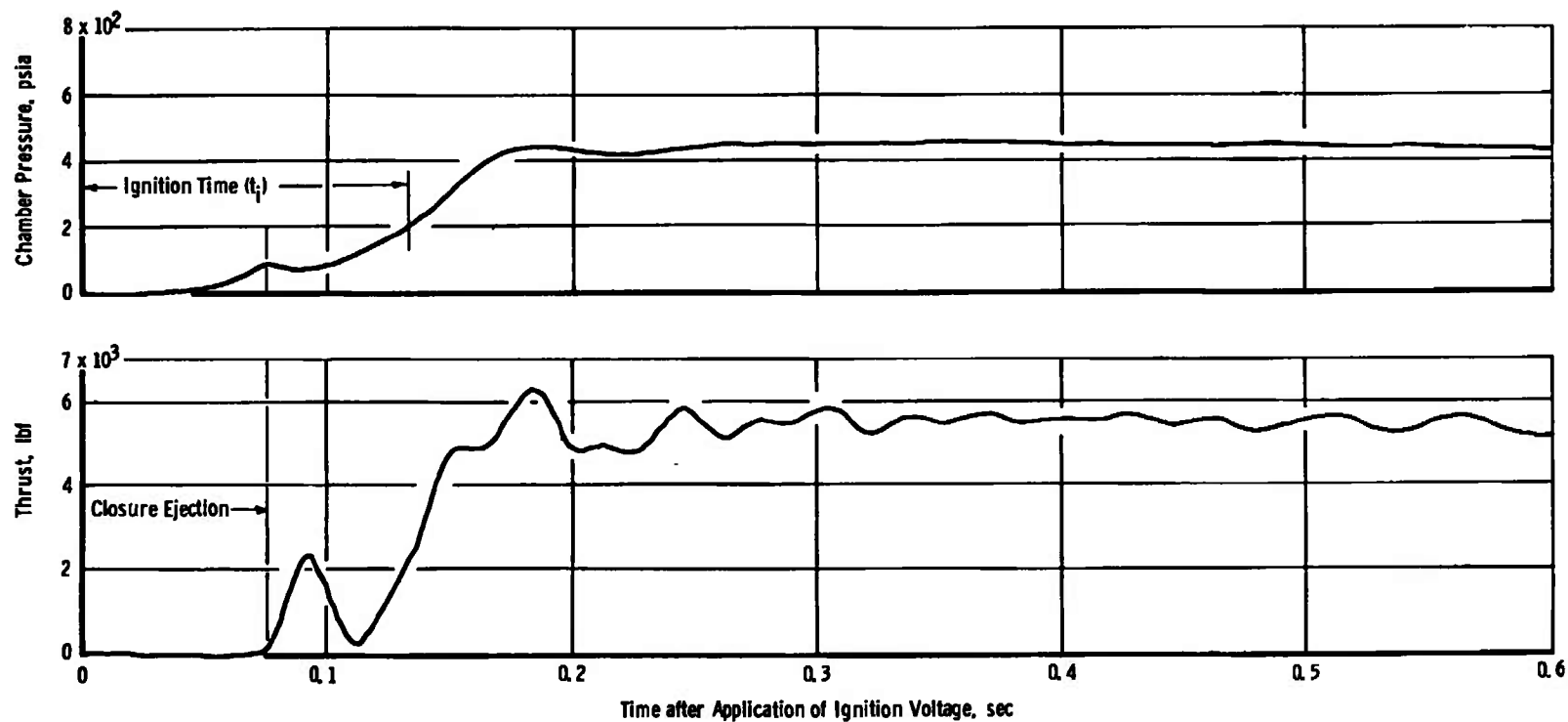


Fig. 4 Variation of Thrust and Chamber Pressure during the Ignition Event

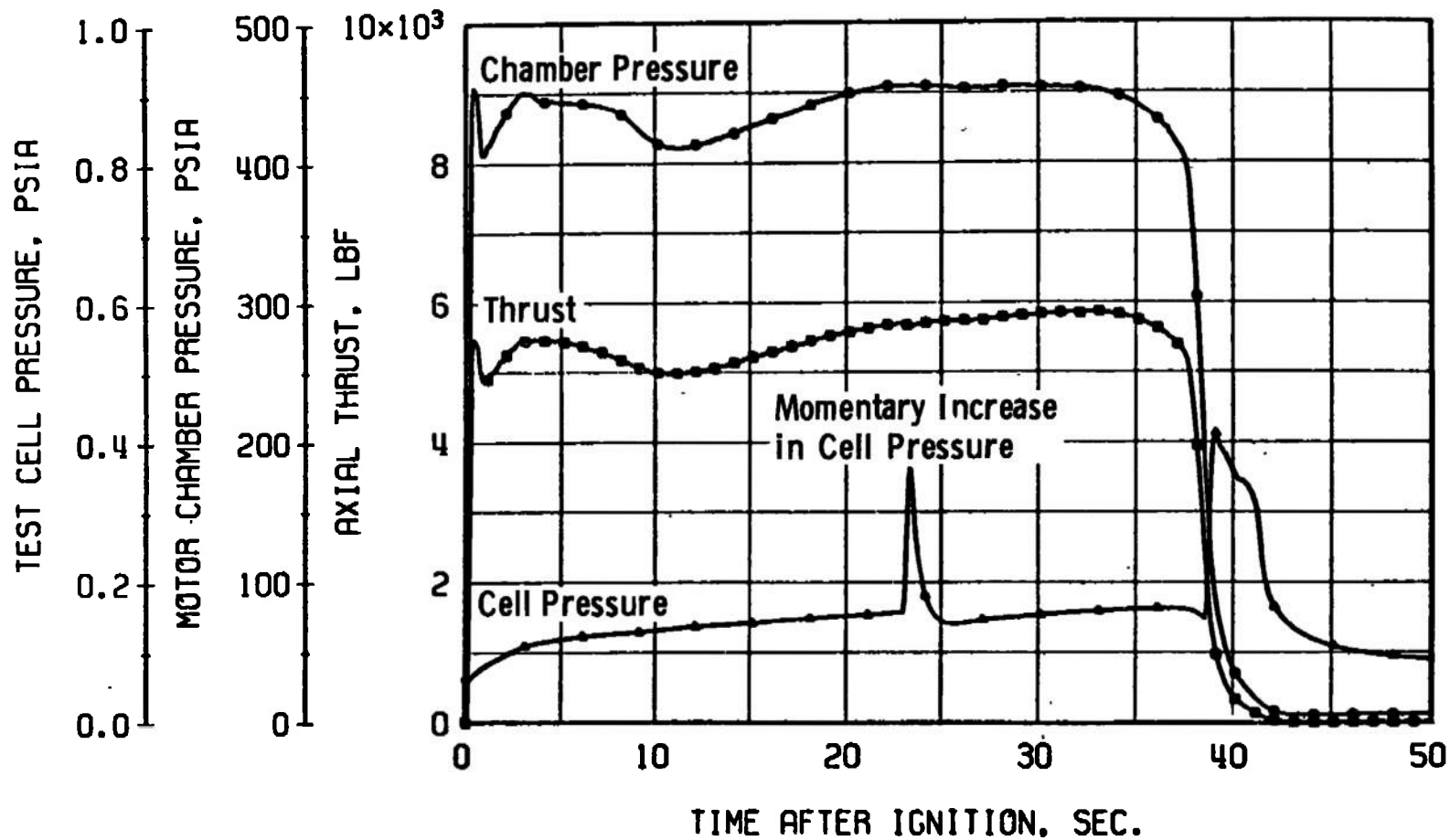
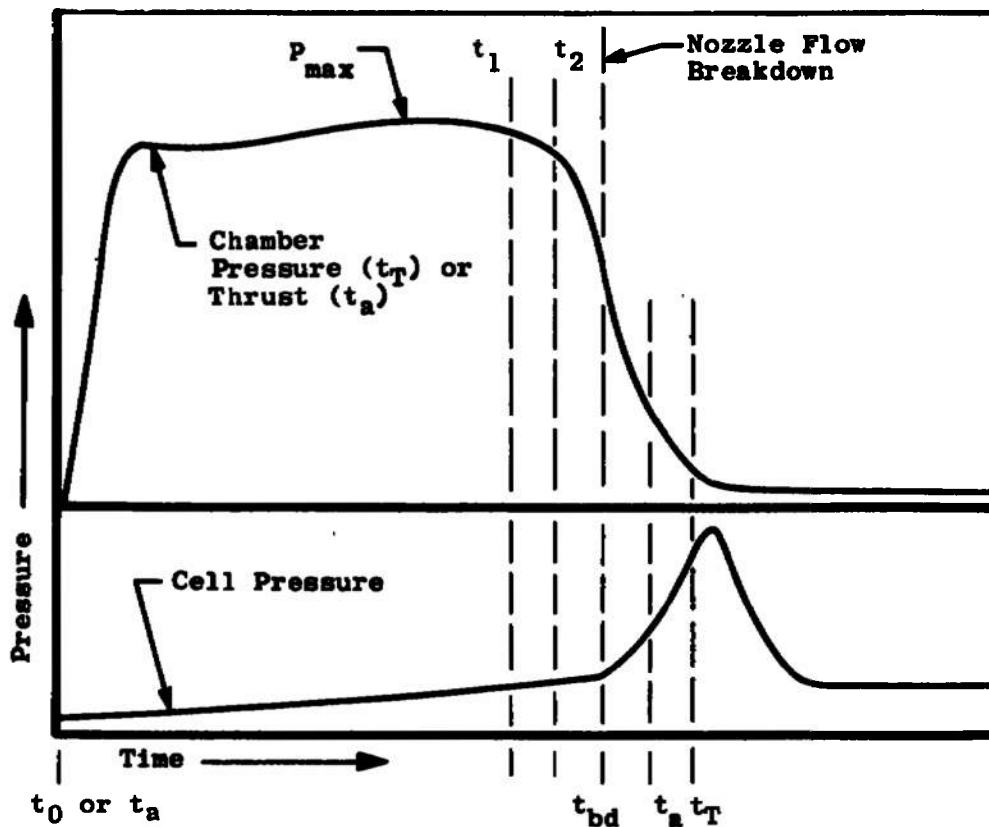


Fig. 5. Variation of Thrust, Chamber Pressure, and Test Cell Pressure during Firing



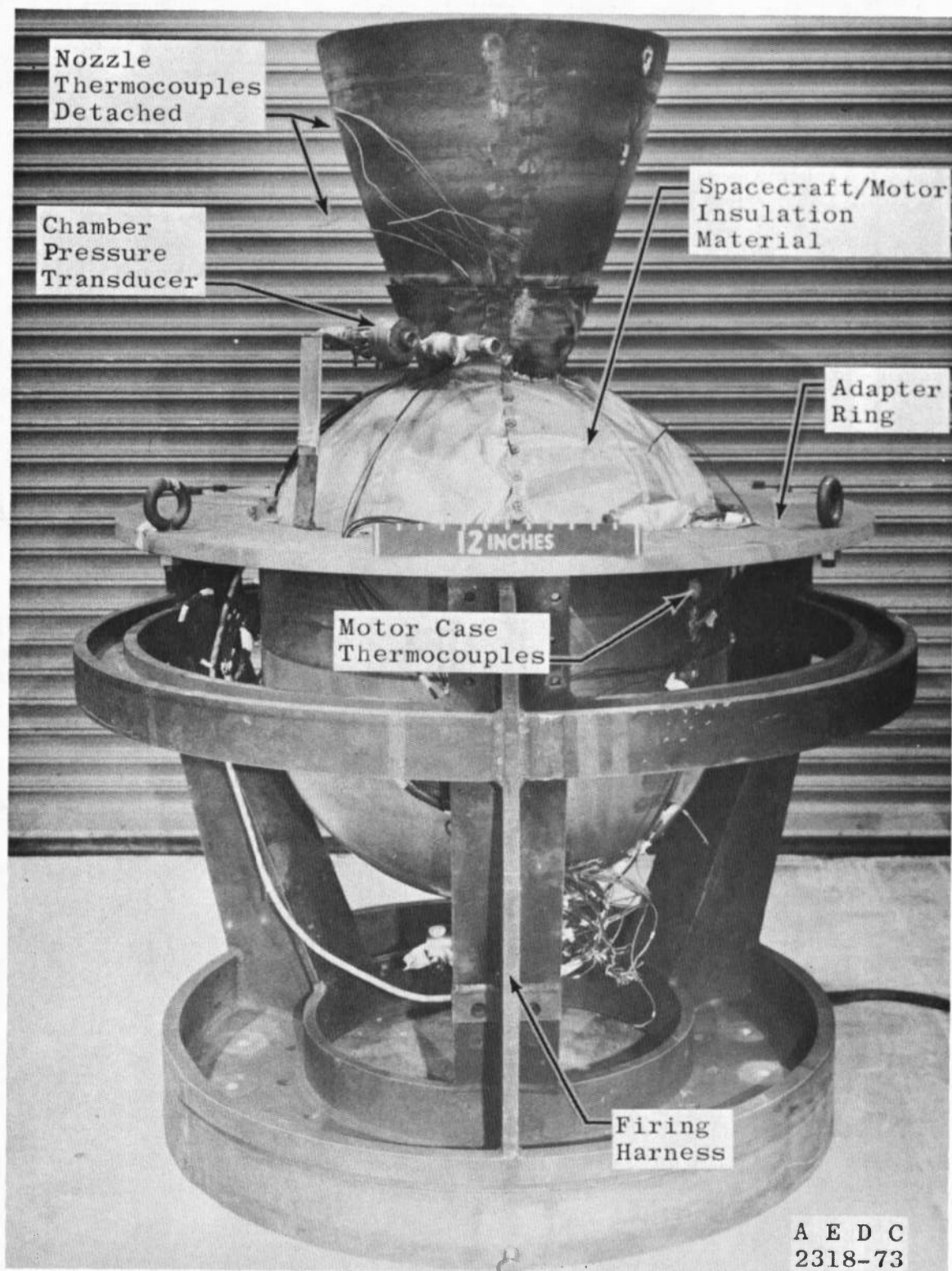
$$I_{vac_total} = \int_{t_0}^{t_{bd}} F dt + A_{ex(avg)} \int_{t_0}^{t_{bd}} P_{cell} dt + \bar{c}_f A_{th(post)} \int_{t_{bd}}^{t_T} P_{ch} dt$$

$$I_{vac_action} = \int_{t_{a_ignition}}^{t_{bd}} F dt + A_{ex(avg)} \int_{t_{a_ignition}}^{t_{bd}} P_{cell} dt + \bar{c}_f A_{th(post)} \int_{t_{bd}}^{t_{a_tailoff}} P_{ch} dt$$

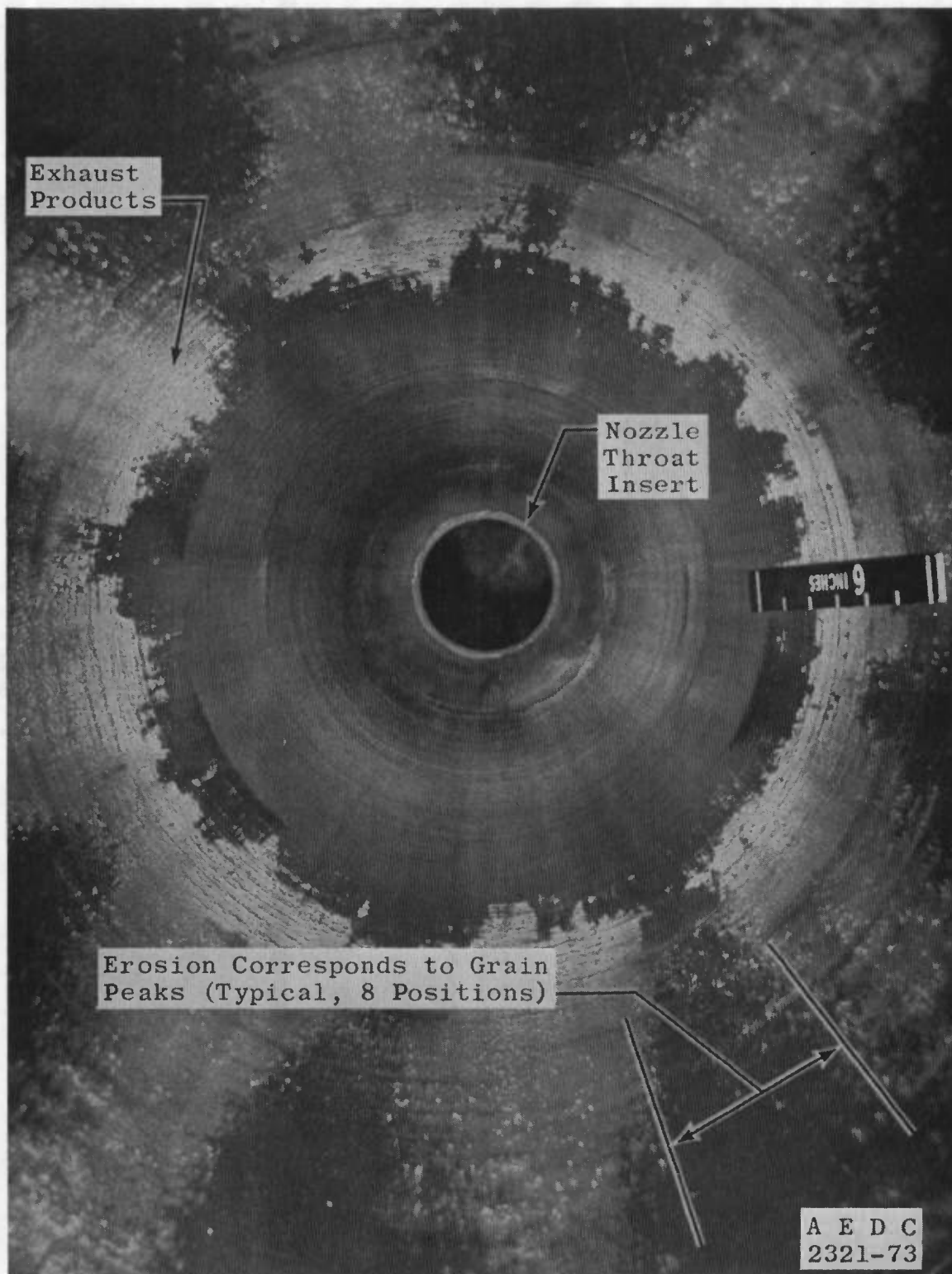
$$\text{where: } \bar{c}_f = \frac{\int_{t_1}^{t_2} F dt + A_{ex_post} \int_{t_1}^{t_2} P_{cell} dt}{A_{t_post} \int_{t_1}^{t_2} P_{ch} dt}, \text{ established from data}$$

during the time interval from 31.75 to 32.75 sec after first indication of chamber pressure.

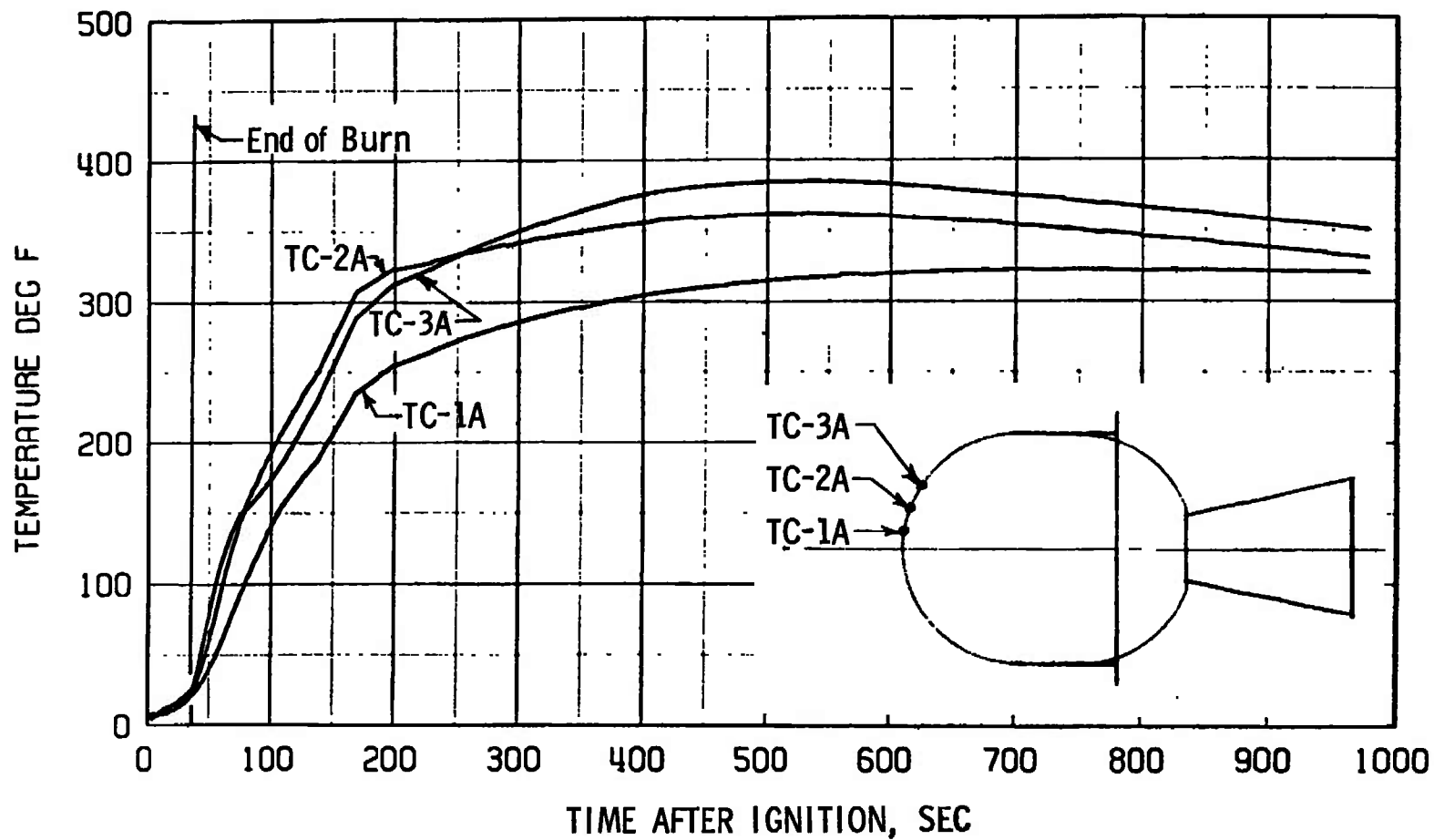
Fig. 6 Definition of Vacuum Total and Action Impulse



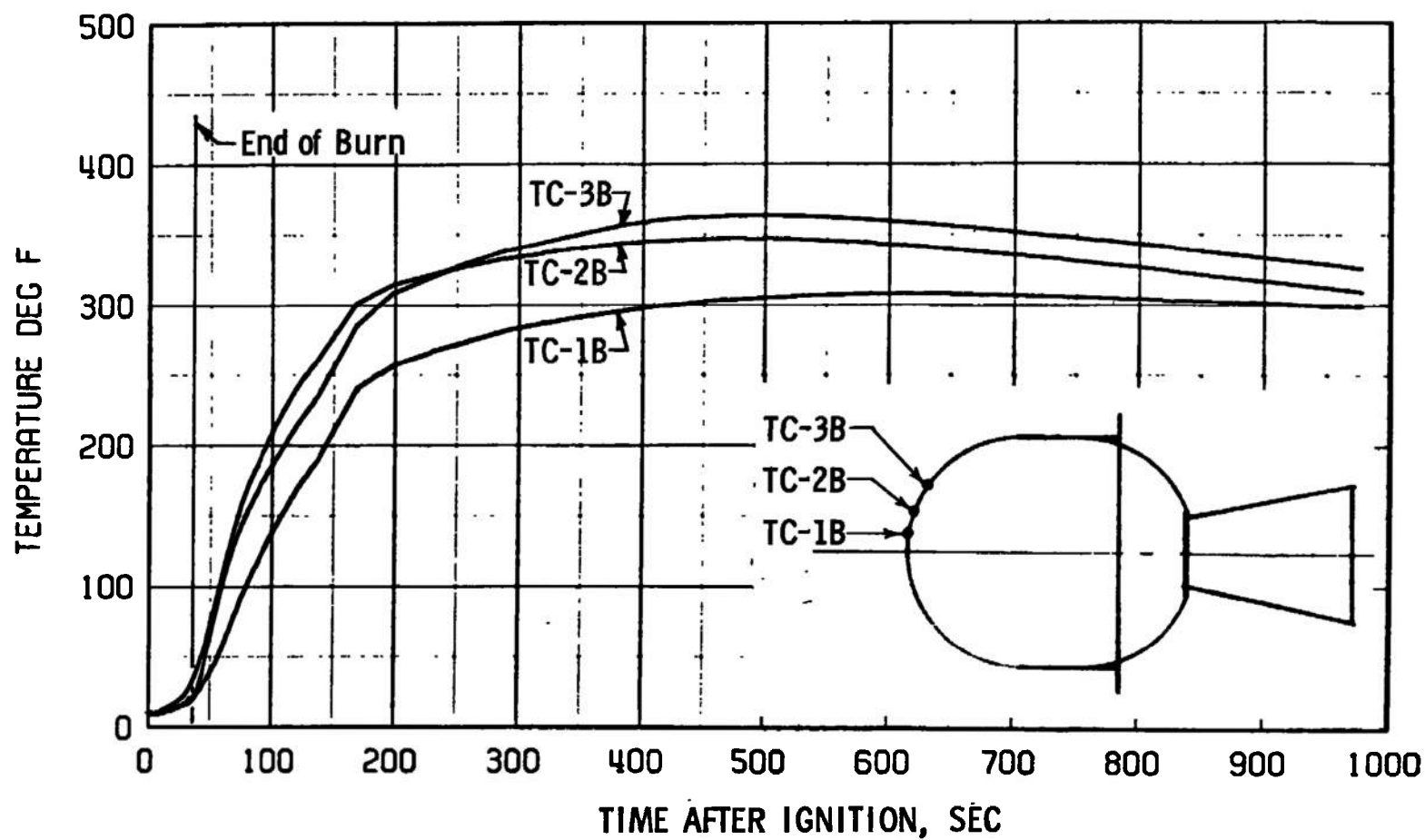
a. Motor Case and Nozzle
Fig. 7 Postfire Photographs of Motor Assembly



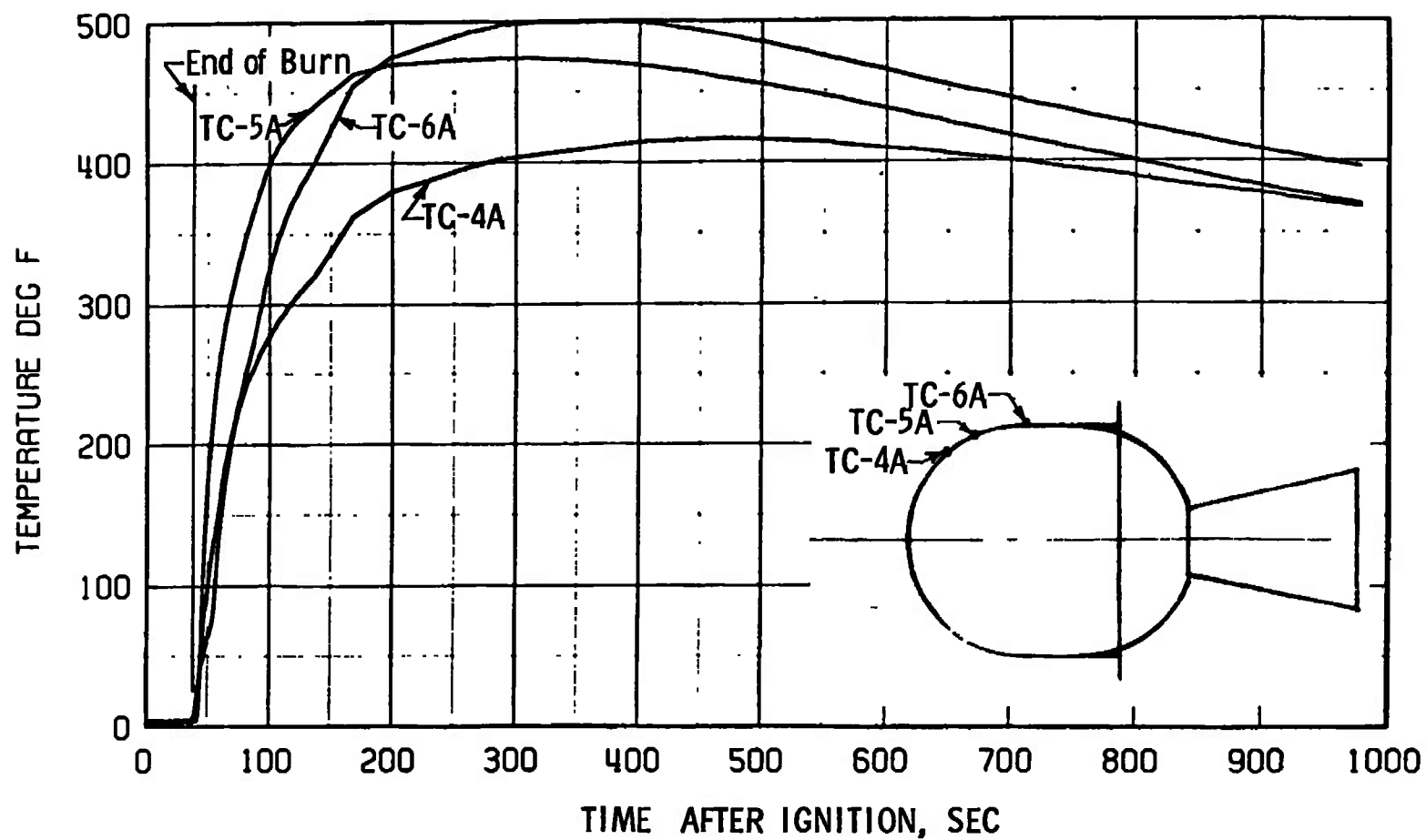
b. Nozzle
Fig. 7 Concluded



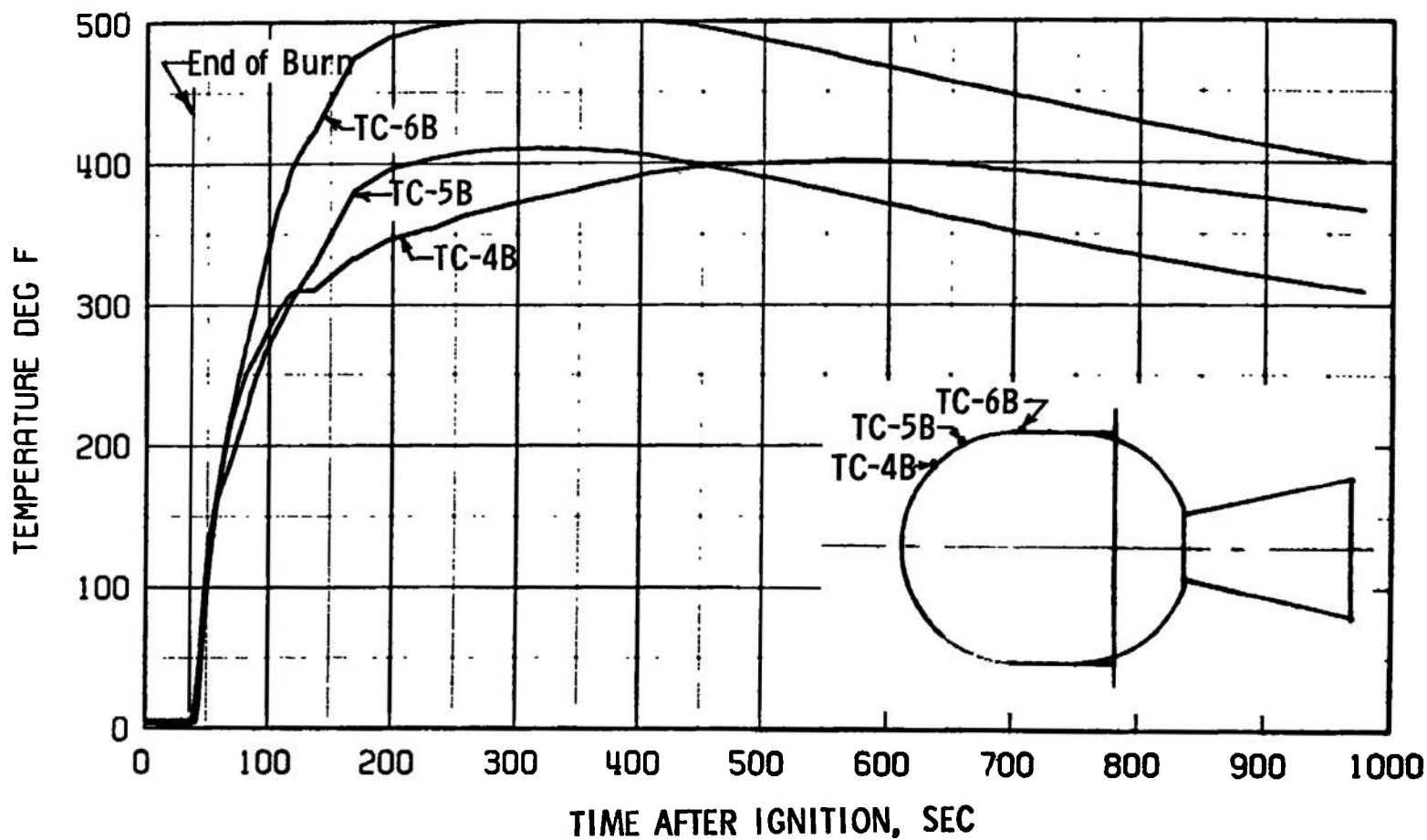
a. Motor Case, TC-1A, TC-2A, and TC-3A
Fig. 8 Motor Temperature Variation with Time



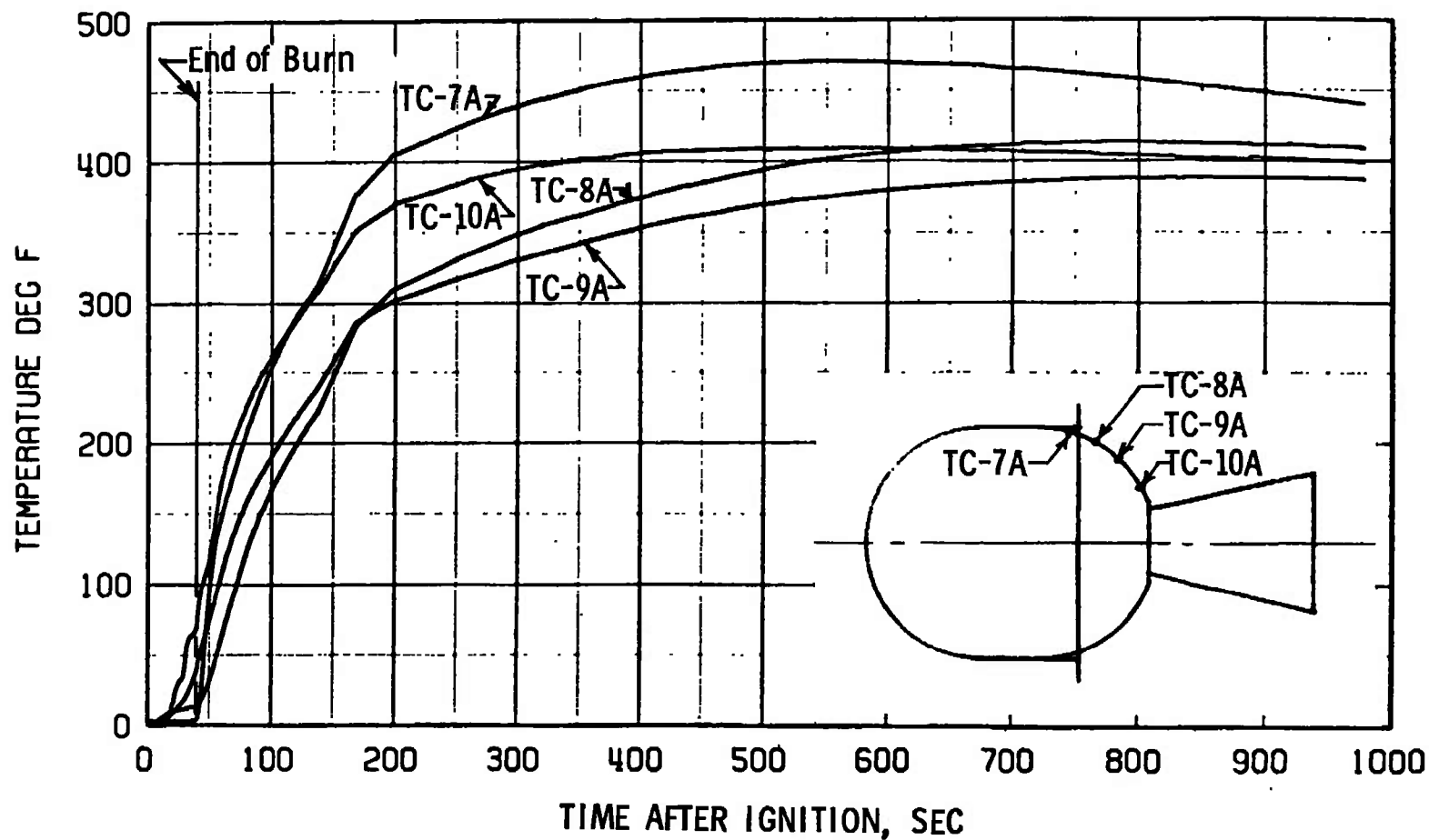
b. Motor Case, TC-1B, TC-2B, and TC-3B
Fig. 8 Continued



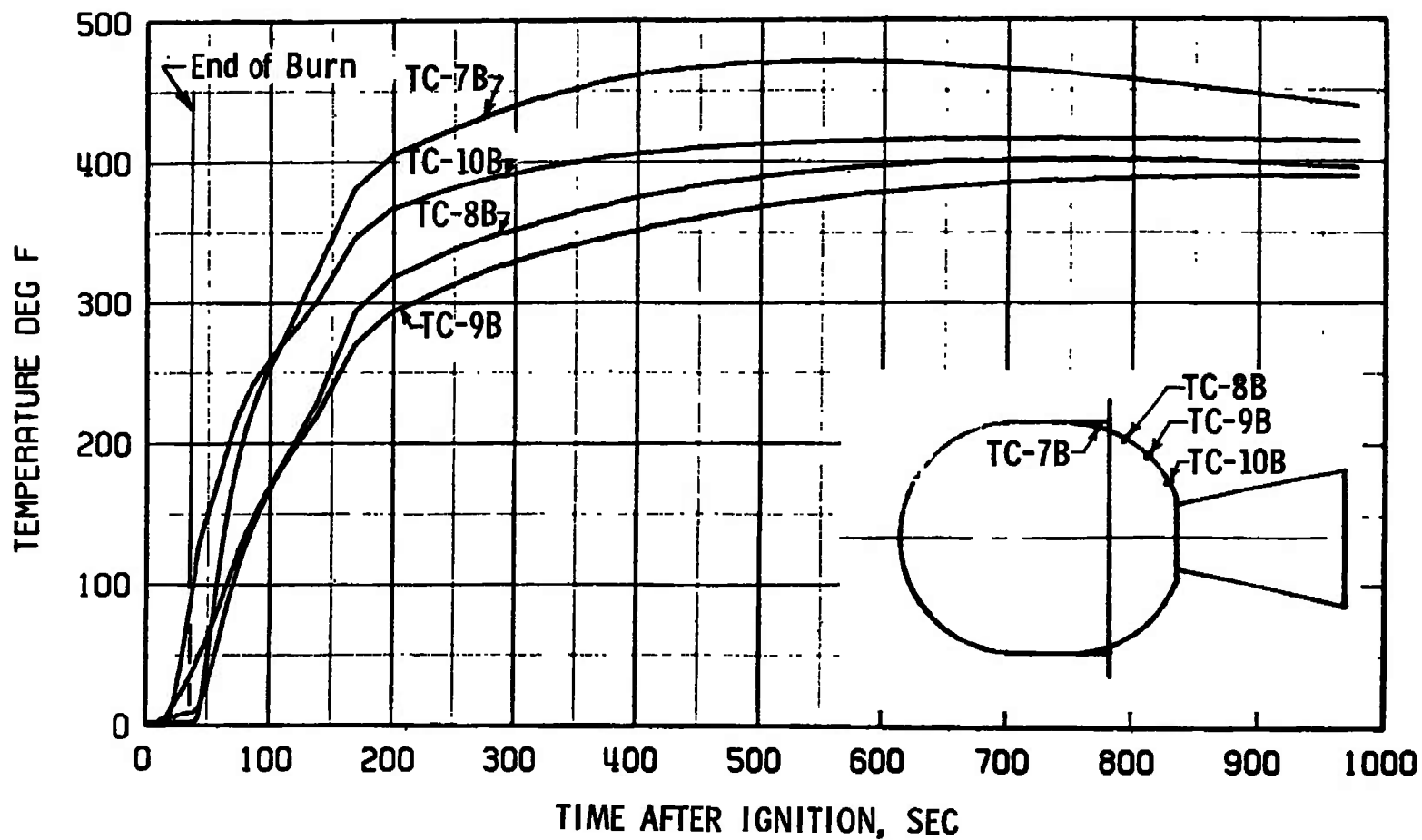
c. Motor Case, TC-4A, TC-5A, and TC-6A
Fig. 8 Continued



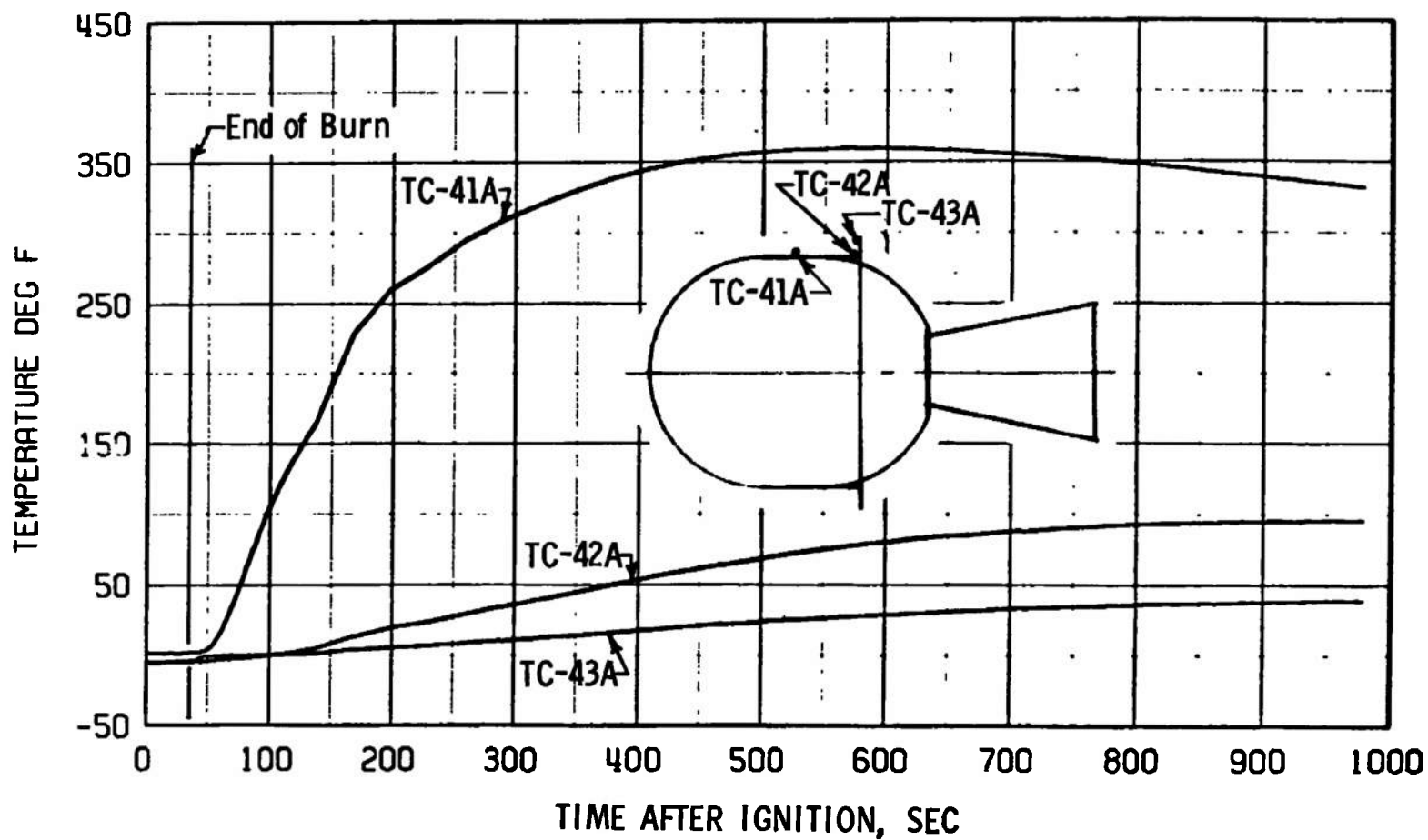
d. Motor Case, TC-4B, TC-5B, and TC-6B
Fig. 8 Continued



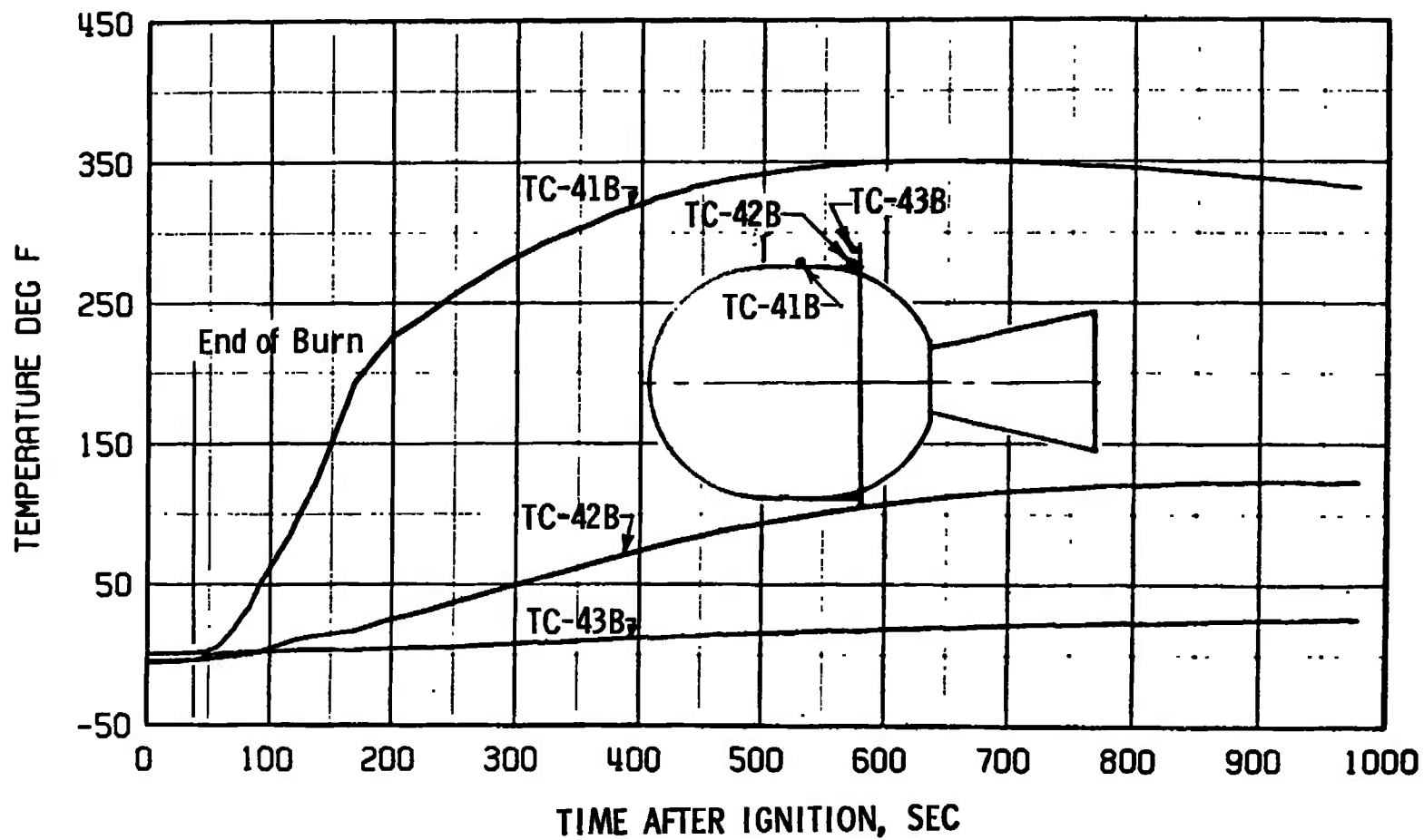
e. Motor Case, TC-7A, TC-8A, TC-9A, and TC-10A
Fig. 8 Continued



f. Motor Case, TC-7B, TC-8B, TC-9B, and TC-10B
Fig. 8 Continued

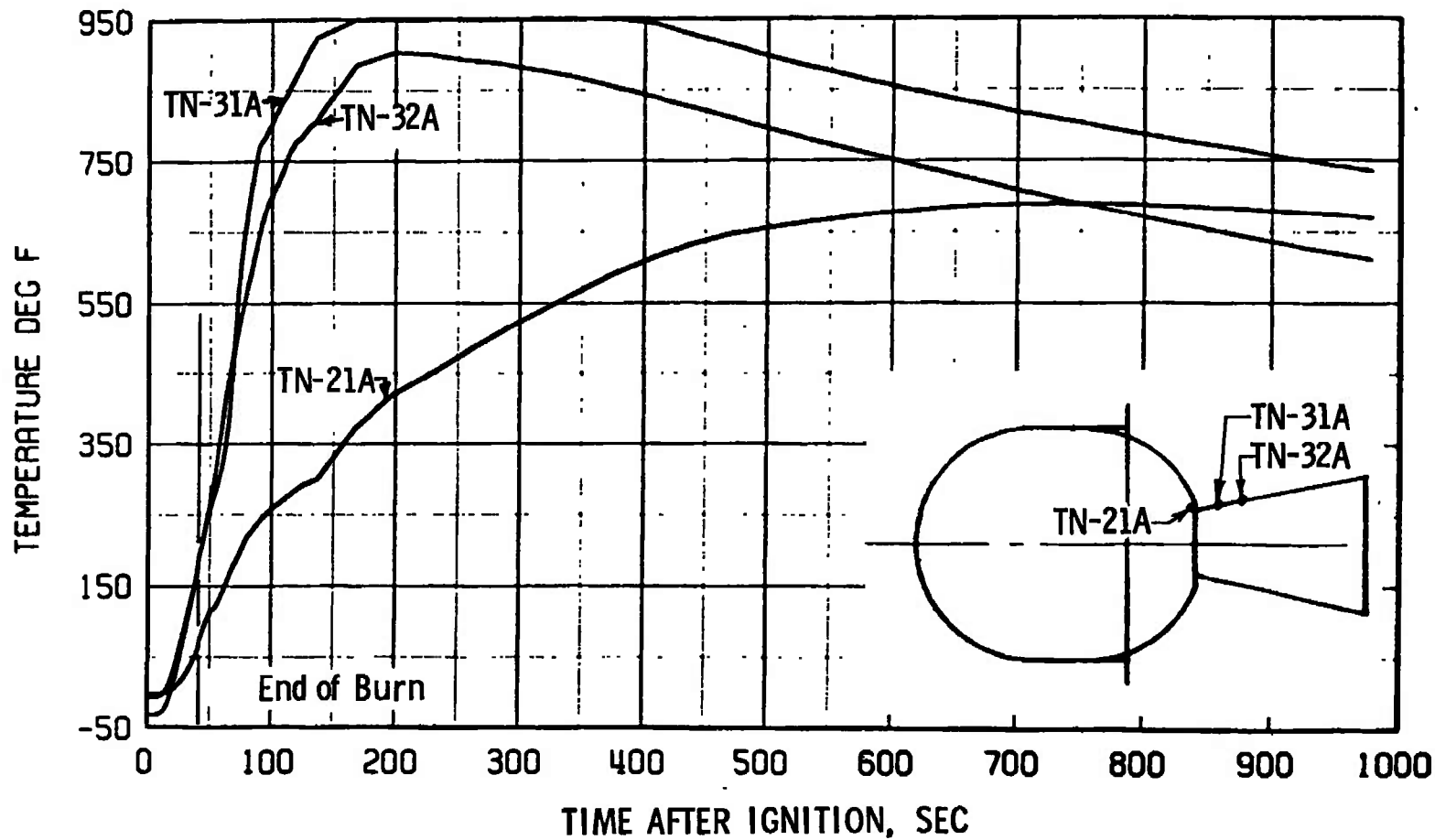


g. Motor Case, TC-41A, TC-42A, and TC-43A
Fig. 8 Continued

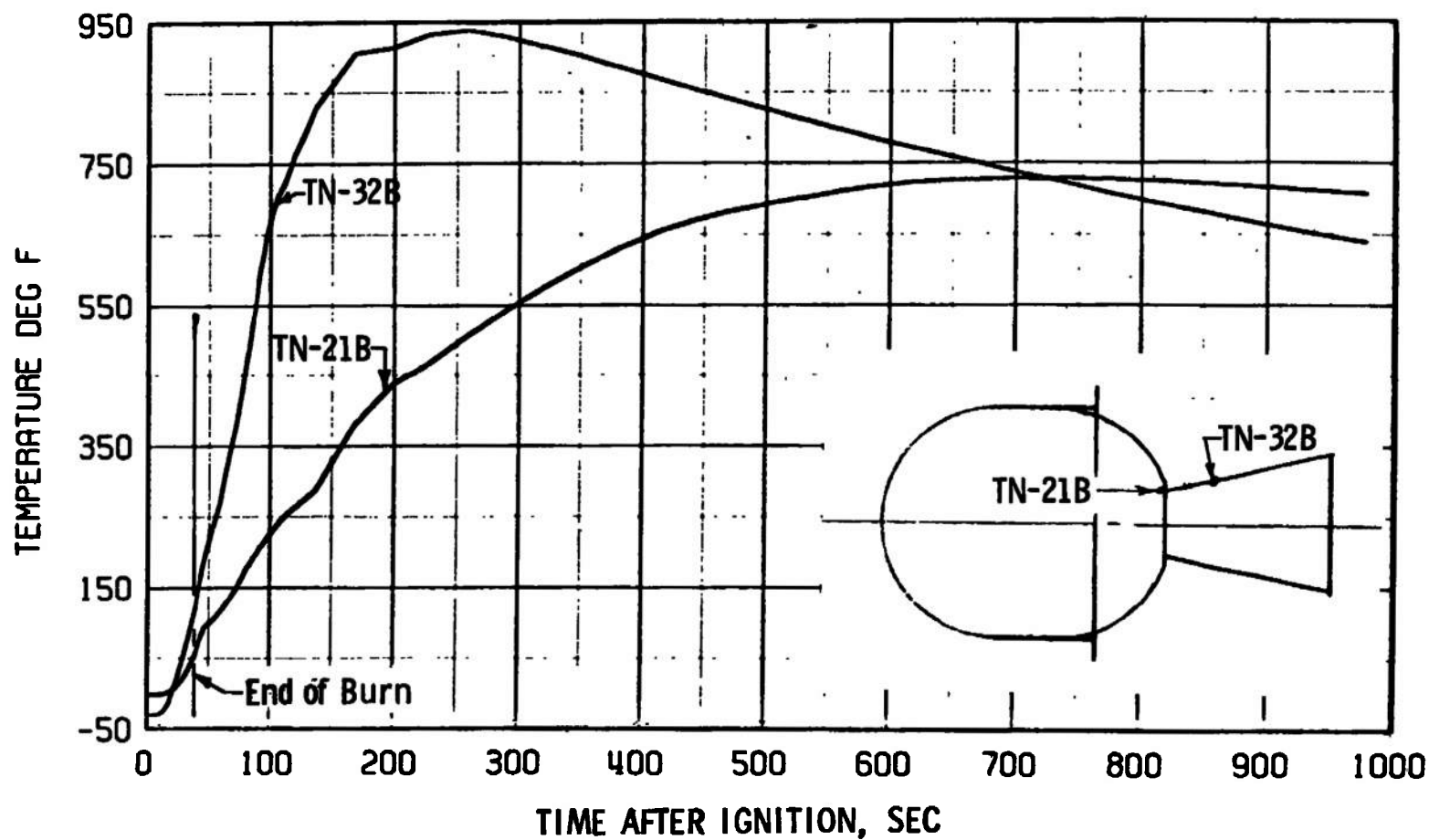


h. Motor Case, TC-41B, TC-42B, and TC-43B

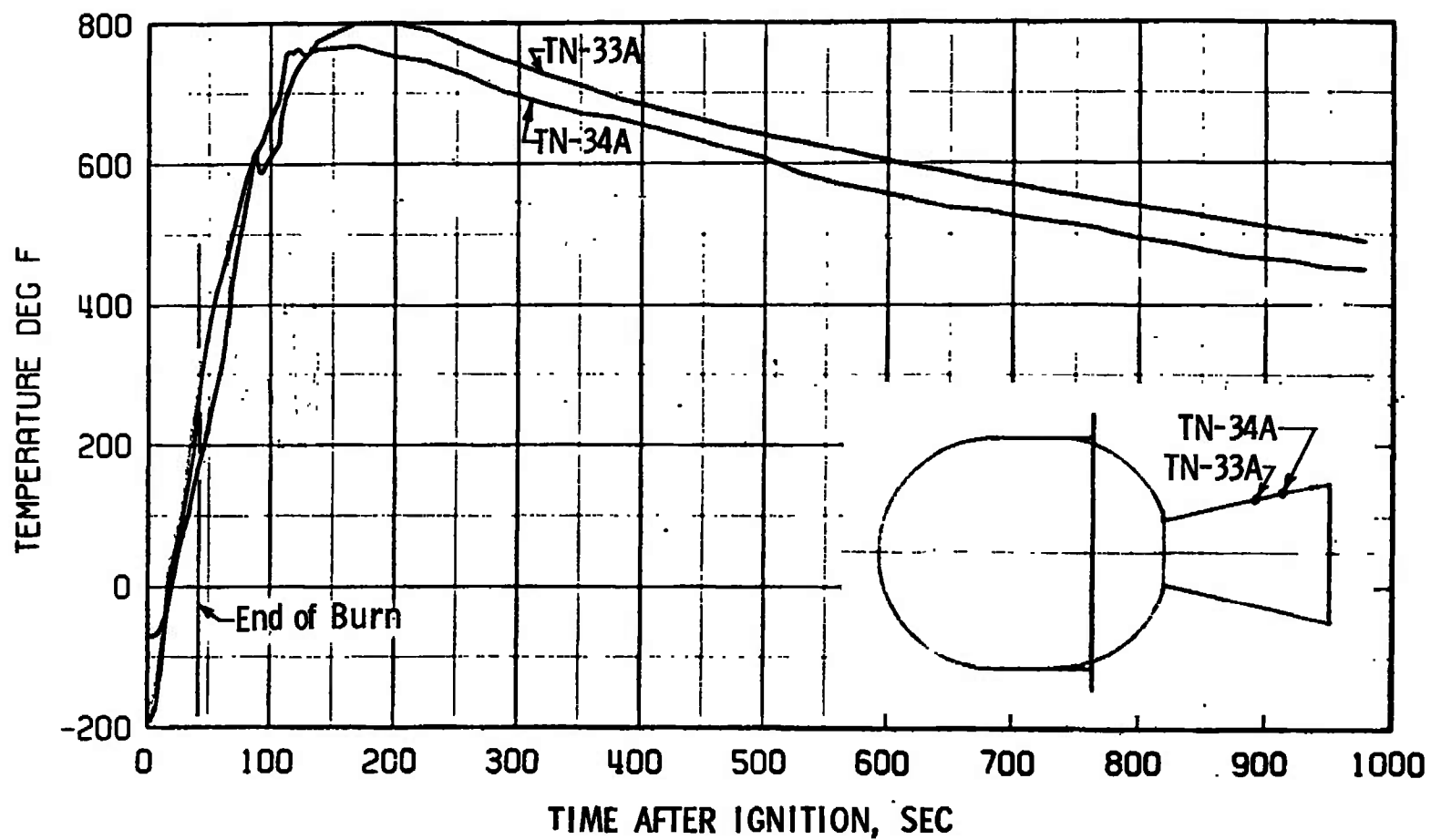
Fig. 8 Continued



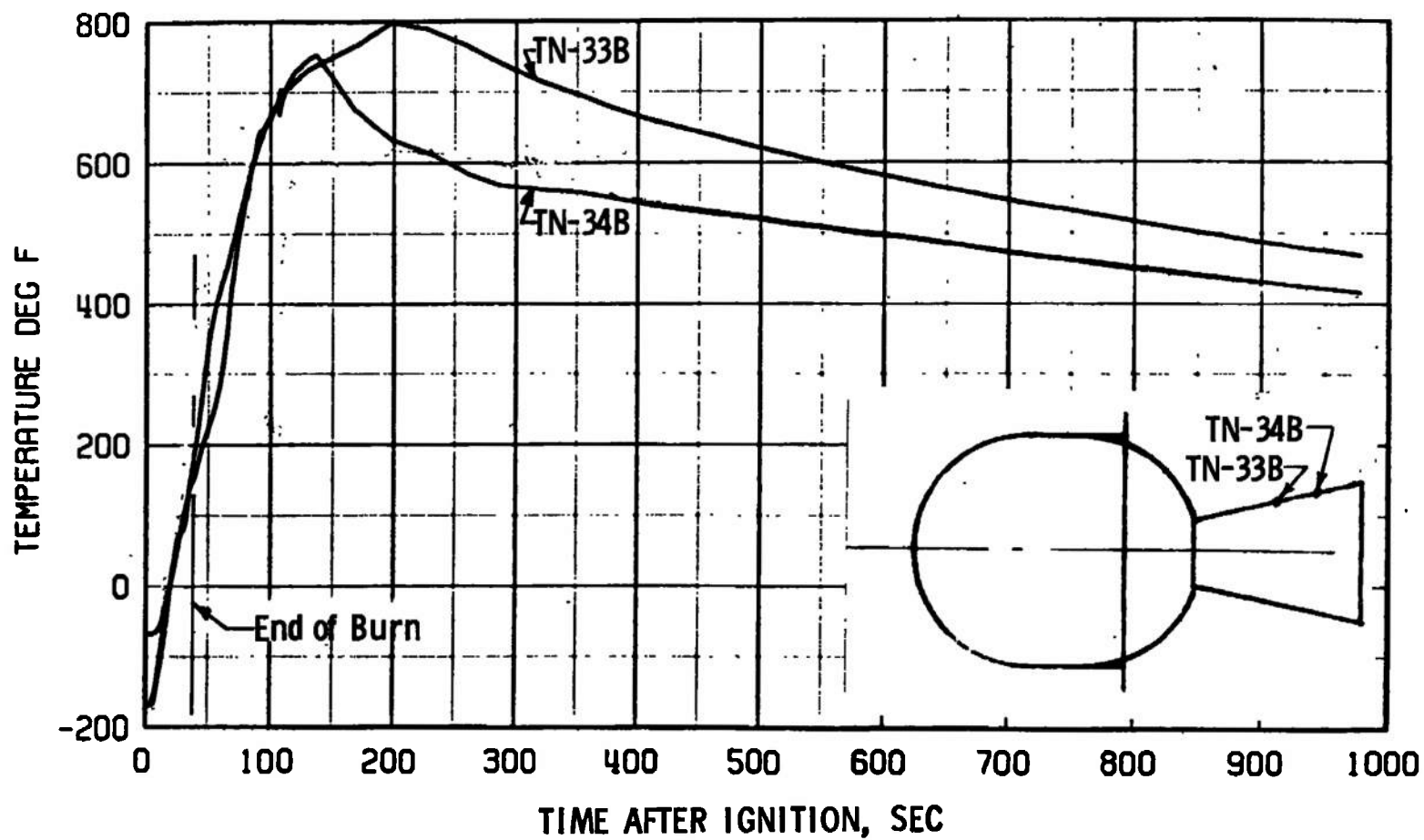
i. Nozzle, TN-21A, TN-31A, and TN-32A
Fig. 8 Continued



j. Nozzle, TN-21B and TN-32B
Fig. 8 Continued



k. Nozzle, TN-33A and TN-34A
Fig. 8 Continued



1. Nozzle, TN-33B and TN-34B
Fig. 8 Concluded

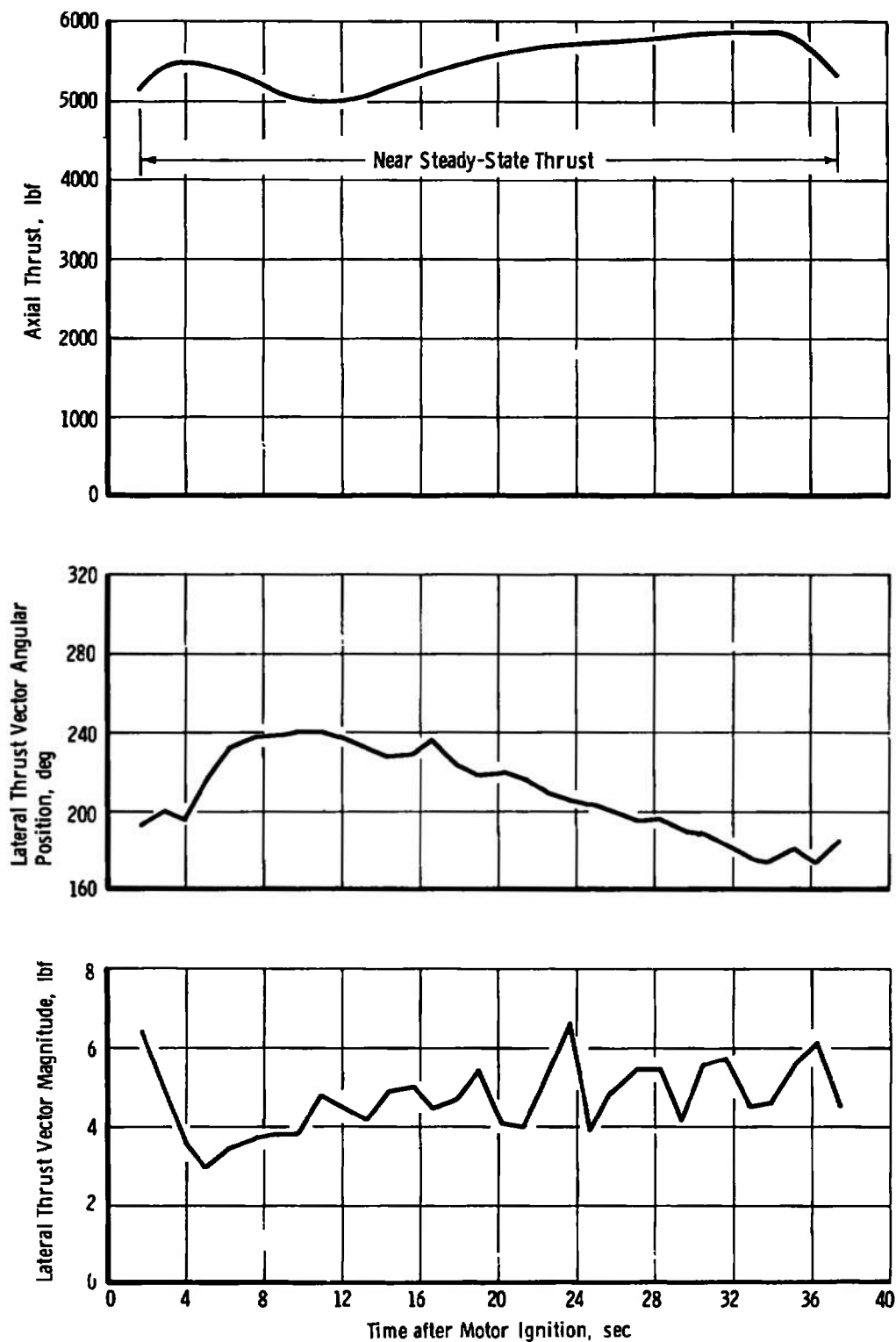


Fig. 9 Variation of Lateral (Nonaxial) Thrust Vector during Firing

TABLE I
INSTRUMENTATION SUMMARY AND MEASUREMENT UNCERTAINTY

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*								Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		Range			
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
Low-Range Chamber Pressure, psia	$\pm(0.1\% + 0.002 \text{ psi})$		31	$\pm(0.04\% + 0.006 \text{ psi})$		$\pm(0.24\% + 0.012 \text{ psi})$		2.5 to 4.0 psia	Bonded Strain-Gage-Type Pressure Transducers	Voltage-to-Frequency Converter onto Magnetic Tape	Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship
Test Cell Pressure, psia	$\pm(0.1\% + 0.002 \text{ psi})$			± 0.24	---	$\pm(0.44\% + 0.004 \text{ psi})$		4 to 40 psia			
Test Cell Pressure Integral, psia-sec	± 0.35	---	125	± 1.9	---	± 2.6	---	0.06 to 0.17 psia			
Chamber Pressure, psia	± 0.15	---	125	± 0.15	---	± 0.45 Note 1	---	400 to 550 psia	Bonded Strain-Gage-Type Force Transducers		
Chamber Pressure Integral, psia-sec	± 0.12	---	31	± 0.15	---	± 0.39 Note 1	---				
Axial Force, lbf	± 0.12	---	375	± 0.1	---	± 0.34	---	4500 to 8000 lbf			
Total Impulse, lbf-sec	± 0.11	---	31	± 0.1	---	± 0.32	---			Sequential Sampling, Millivolt-to-Digital Converter, and Magnetic Tape Storage Data Acquisition System	In-Place Application of Multiple Force Levels Measured with Force Transducers Calibrated in the Standards Laboratory
Lateral Thrust Vector, lbf	---	$\pm 0.21 \text{ lbf}$	7	---	$\pm 0.57 \text{ lbf}$	---	$\pm 1.07 \text{ lbf}$	3.0 to 6.6 lbf			
Motor Temperature, °F	---	$\pm 0.25^\circ\text{F}$	95	---	$\pm 2.5^\circ\text{F}$	---	$\pm 3.0^\circ\text{F}$	0 to 530°F			
				$\pm(1.2^\circ\text{F} + 0.25\%)$		$\pm(1.7^\circ\text{F} + 0.25\%)$		530 to 1000 °F	Chromel-Alumel Temperature Transducers		Millivolt Substitution Based on the NBS Temperature versus Millivolt Tables
Time Interval, msec	---	$\pm 0.25 \text{ msec}$	31	---	$\pm 0.1 \text{ msec}$	---	$\pm 0.5 \text{ msec}$	---	Time Pulse Generator	Photographically Recording Galvanometer Oscillograph	Time Pulse Generator Calibrated in the Standards Laboratory
Weight, lbm	--	$\pm 0.015 \text{ lbm}$	31	---	$\pm 0.048 \text{ lbm}$	---	$\pm 0.078 \text{ lbf}$	400 to 1200 lbm	Beam-Balance Scales	Visual Readout	In-Place Application of Deadweights Calibrated in the Standards Laboratory

*Reference: CFIA No. 180, "ICRPG Handbook for Estimating the Uncertainty in Measurements made with Liquid Propellant Rocket Engine Systems," April 30, 1969.

Note: 1. Chamber Pressure Measurement Uncertainty Estimate Based on P_{ch} - 2 only.

TABLE II
SUMMARY OF TE-M-616-01 MOTOR PERFORMANCE

Test Number	01
Motor Serial Number	D2
Test Date	3/24/73
Average Motor Spin Rate during Firing, rpm	105
Motor Case Temperature at Ignition, °F	3
Ignition Time (t_i), sec ¹	0.132
Action Time (t_a), sec ²	38.9
Total Time (t_T), sec ³	43.5
Simulated Altitude at Ignition, ft	121,000
Average Simulated Altitude during t_a , ft	103,000
Measured Total Impulse (based on t_a), lbf-sec	
Average of Four Channels of Data	208,153
Maximum Channel Deviation from Average, percent	0.01
Chamber Pressure Integral (based on t_a), psia-sec	16.888 ⁴
Cell Pressure Integral (based on t_a), psia-sec	
Average of Two Channels of Data	5.5666
Maximum Channel Deviation, percent	1.21
Vacuum Total Impulse (based on t_a), lbf-sec	210,949
Vacuum Total Impulse (based on t_T), lbf-sec	212,321
Vacuum Specific Impulse (based on t_a), lbf-sec/lbm	
Based on the Manufacturer's Stated Propellant Weight	287.07
Based on Expended Mass (AEDC)	284.39
Vacuum Specific Impulse (based on t_T), lbf-sec/lbm	
Based on the Manufacturer's Stated Propellant Weight	288.94
Based on Expended Mass (AEDC)	286.24
Average Vacuum Thrust Coefficient (C_F)	
Based on t_a and Average Pre- and Postfire Areas	1.819

¹Ignition time is the time interval from application of ignition voltage to when chamber pressure has risen to 200 psia.

²Action time is the time interval from first indication of thrust until the delivery of 99.5 percent of total impulse.

³Total time is the time interval beginning with the first rise in chamber pressure and ending when chamber pressure reaches 1 psia on the descending portion of the pressure versus time curve.

⁴Only one chamber pressure measurement.

TABLE III
SUMMARY OF TE-M-616-01 MOTOR PHYSICAL DIMENSIONS

Test Number - RA202	01
Motor Serial Number	D2
Test Date	3/24/73
Motor Spin Rate, rpm	105
AEDC Prefire Motor Weight, lbm*	1197.46
AEDC Postfire Motor Weight, lbm*	455.69
AEDC Expended Mass, lbm	741.77
Manufacturer's Stated Propellant Weight, lbm**	734.84
Nozzle Throat Area, in. ²	
Prefire**	6.521
Postfire	7.206
Change from Prefire Measurement, percent	+10.5
Nozzle Exit Area, in. ²	
Prefire	292.145
Postfire	292.099
Change from Prefire Measurement, percent	-0.01

*Includes Igniter Weight and AEDC Firing Harness

**Supplied by Motor Manufacturer

UNCLASSIFIED

Security Classification

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13. ABSTRACT One Thiokol Chemical Corporation TE-M-616-01 solid-propellant rocket motor was successfully fired at an average simulated altitude of 103,000 ft while spinning at 105 rpm after being temperature conditioned at $5 \pm 5^{\circ}\text{F}$ for a minimum of 34 hr. In addition, the aft six inches of the nozzle exit cone was cooled to about -195°F immediately prior to ignition. The program objectives were to determine vacuum ballistic performance, altitude ignition characteristics, motor temperature-time histories, structural integrity of motor components, and the lateral (nonaxial) thrust vector. The applicable data were used to demonstrate compliance of the motor with requirements set forth in Communication Research Centre Specification SS09-04.			

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KEY WORDS

LINK A

LINK B

LINK C

ROLE

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ROLE

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ROLE

WT

TE-M-616-01

solid propellant rocket motor

ballistics

altitude simulation

structural stability

spin stabilization

AFSC
Amold AFS Tenn

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